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The design and evaluation of transmit and receive antennas for an ionospheric communications probe system: A. Multiband Dipole Antenna

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The Design and Evaluation of Transmit and Receive Antennas for an Ionospheric Communications Probe System: A. Multiband Dipole Antenna

by

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TLE (Include Security Classification) THE DESIGN AND EVALUATION OF TRANSMIT AND RECEIVE ENNAS FOR AN IONOSPHERIC COMMUNICATIONS PROBE SYSTEM: A. MULTIBAND OLE ANTENNA

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ABSTRACT

This thesis reports the design, performance evaluation and construction of a transmitting antenna for an HF communications probe system.

A short range ionospheric communication link between Monterey, CA, (transmit site) and San Diego, CA, (receive site) was established to test the software and hardware of this probe system.

The Multiband Dipole Antenna was selected as the more practical antenna for this link, using less real estate and support structure than other alternatives. The antenna was constructed and installed at the NPS beach site where the ground constants were measured accurately.

Numerical Electromagnetics Code (NEC) analysis and measurements show that the antenna operates with low input VSWR (< 1.5), is insensitive to electrical ground characteristics and has excellent radiation patterns for short range ionospheric communication links. Based on the observed signal strengths at San Diego, the antenna appears to be performing very well.

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I. INTRODUCTION

The Navy's Polar Equatorial NVIS (Near Vertical Incidence Skywave) EXperiment (PENEX) project requires accurate field strength data for High-Latitude HF ionospheric communication links. The transmit site of these links will be at Cape Wales, AK, and the receive sites will be at Fairbanks, AK, Seattle, WA, San Diego, CA, and State College, PE.

In order to test the software and hardware developed by the PENEX team, a short range ionospheric communication link between Monterey, CA (transmit site), and San Diego, CA (receive site) was established. After the trials are completed, the equipment will be moved to appropriate locations for final installation and testing.

The purpose of this thesis is to design, evaluate the performance and construct a Multiband Dipole Antenna to support the transmitting requirements of the PENEX project. The antenna will operate at the three assigned frequencies of 5.6, 11 and 16.8 MHz. For an ionospheric communication link, the shape of radiation pattern of the antenna is critical and is influenced by the antenna height above ground and the electrical characteristics of the ground beneath the antenna. The antenna was constructed based on the requirements of the link and installed at the NPS beach (Monterey) transmitter site.

Chapter II describes the effects of the earth on HF wire antennas, the ionosphere, resonance of $\lambda/2$ dipoles and the theory of the Multiband Dipole Antenna.

Chapter III presents the method used to accurately determine the ground constants of the NPS beach site and the results of these measurements.

Chapter IV describes the design and construction of the antenna.

Chapter V explains multiband dipole modeling, using NEC. The performance parameters calculated by NEC, the measured results and a comparison of the two are included.

Chapter VI presents conclusions and recommendations regarding the design and implementation of the antenna.

II. THEORETICAL BACKGROUND

A. THE EFFECTS OF THE EARTH ON HF ANTENNAS

HF antennas, in most cases, operate near the earth which acts as an imperfectly reflecting mirror for waves radiated from the antenna at angles lower than the horizon. In order to analyze the performance of an antenna operating at height h over the earth, image theory is applied. In image theory, the reflected wave is assumed to be radiated by a virtual antenna (image) at depth h which is electrically "inverted" from the antenna (Figure 1).

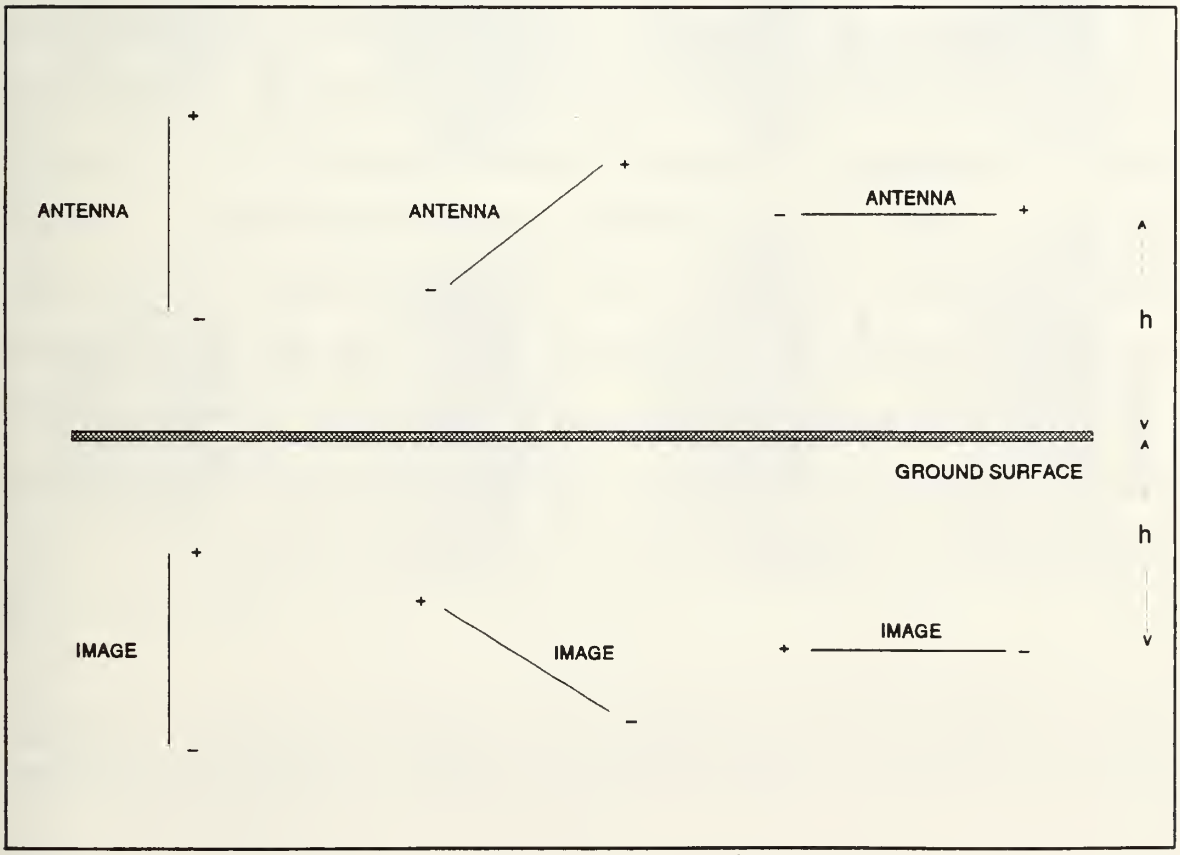

Figure 1: Horizontal, tilted and vertical half-wave antennas and their images.

Some factors that influence the operation of the antenna over the earth are the orientation of the antenna with respect to the ground (vertical or horizontal orientation), the height of the antenna and the electrical characteristics of the ground. Currents in the vertical antenna and their images flow in the same direction, but in the horizontal antenna they flow in the opposite direction [Ref. 1].

The amplitude and phase of the reflection of the image currents is dependent on the earth's conductivity and permittivity. Higher electric ground constant values yield higher reflection coefficients (maximum is -1 for perfect ground), and thus stronger total electric fields from the antenna [Ref. 2].

Another factor affecting the operation of antennas over earth is the position of the antenna relative to the earth which influences the shape and magnitude of the radiation pattern. Figure 2 shows several radiation patterns of a half-wave horizontal dipole at various heights above the ground. The solid curves are for perfect earth, and the shaded curves for "average ground" (ϵ_r=15, σ=5 mS/m) for 14 MHz. As the height increases, more minor lobes are formed. The number of minor lobes are proportional to the factor h/λ.

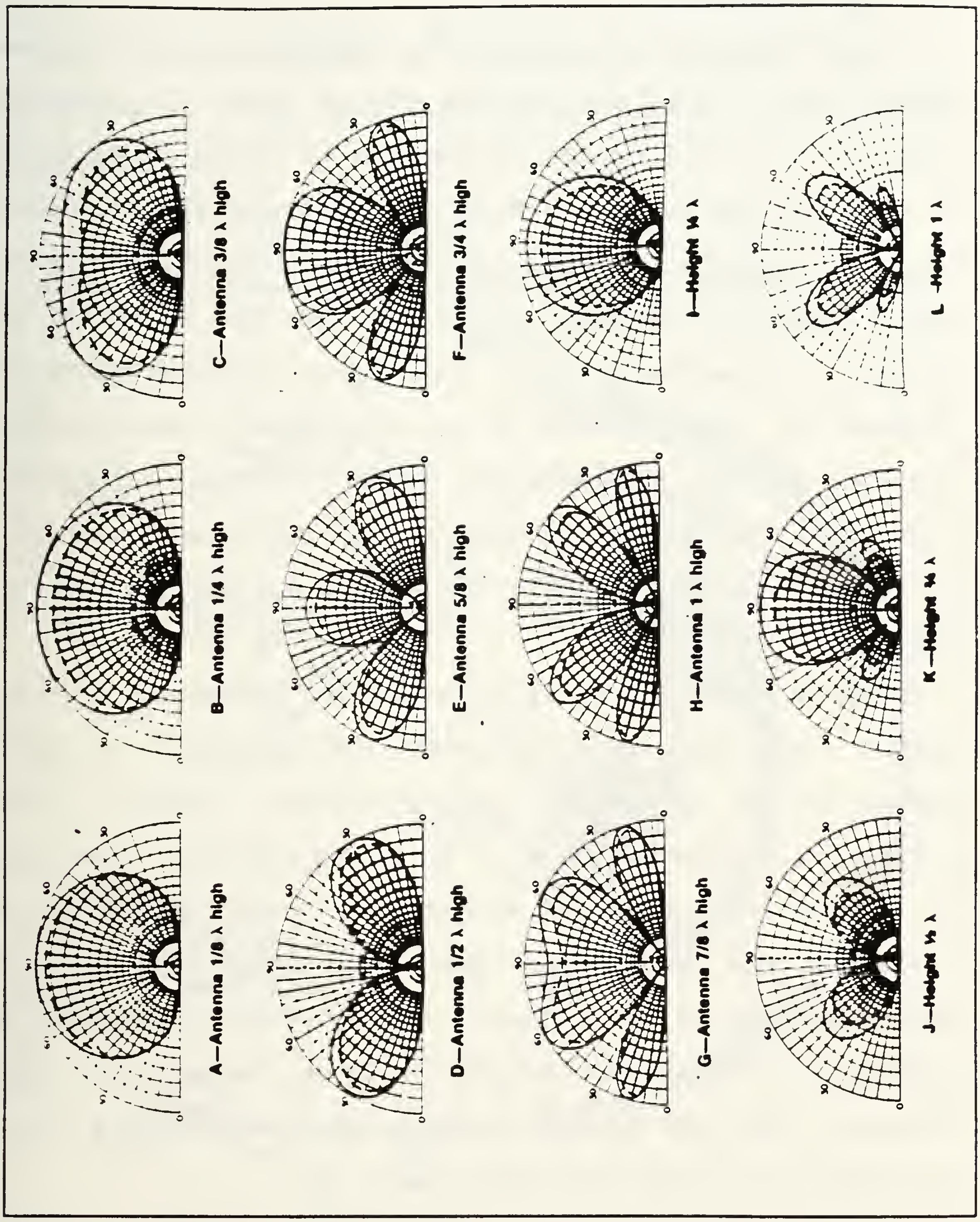

Figure 2: Typical radiation patterns for horizontal dipoles over ground (the patterns A-H are broadside while the patterns I-L are endfire to the dipole).

B. THE IONOSPHERE

The ionosphere is a region of ionized gas located between 80 to 500 km above the surface of the earth. The electron density in the undisturbed ionosphere is of the order of 10^2 to 10^7 electrons per cubic centimeter. The ionosphere consists of three region of different electron density called the D,E and F layers. The F-layer splits into two layers, called the F_1 and F_2, during the daytime. The D-layer disappears at night (Figure 3). The ionization of gas molecules is controlled by sunlight causing the electron density of the ionospheric layers to vary with the time of day, the season and over periods of several years in accordance with solar activity [Ref. 3].

The ionosphere acts as a refracting medium on HF radio waves, controlled by conductivity and permittivity, which depend on the constantly changing electron density. If the transmitting antenna radiates in all directions, some rays will enter the ionosphere at just the right angles and be refracted back down toward the earth. Other rays will not return and will "lost in space". For a given maximum electron concentration N_{MAX} of an ionospheric layer, the Maximum Usable Frequency (MUF) is related to the incident wave angle ϕ_i at the ionosphere by the relationship [Ref. 4]:

$$MUF = 9\sqrt{N_{MAX}}\ \sec(\phi_i). \tag{1}$$

This formula is known as the Secant Law and shows that the MUF varies with the path ($\sec \phi_i$) and depends on N_{MAX} which varies with time..

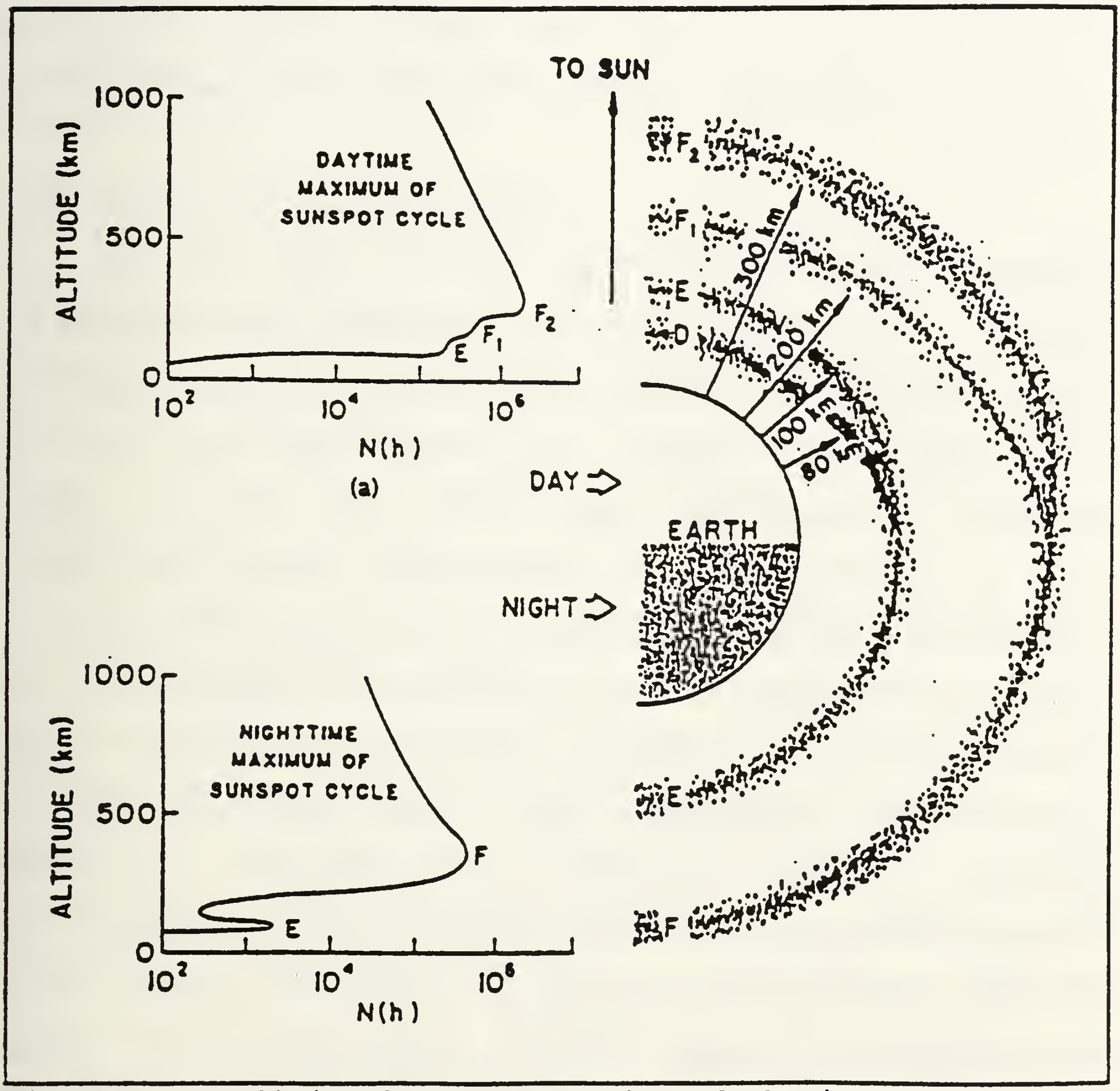

Figure 3: Traditional representation of the ionosphere.

C. THE MULTIBAND DIPOLE ANTENNA

An HF antenna can be considered as a circuit which presents an impedance at its terminals. The impedance of the antenna is the ratio of the applied voltage to the current at the feed point. In general, the impedance is a complex number. The real part of the input impedance is called the radiation resistance. The radiation resistance of the antenna is effected by its height above ground and by the location of the feed point.

If the input current and voltage are exactly in phase, the impedance is purely resistive, and the antenna is said to be resonant. If the antenna is out of resonance, the impedance at its terminals is not purely resistive but is complex. When the length of a dipole antenna is slightly less that $\lambda/2$, the antenna is resonant. The frequency where this occurs is called the resonant frequency. At the resonant frequency the input impedance of the dipole is equal to the radiation resistance and if it is equal to the characteristic impedance of the transmission line, the antenna accepts all of the input signal power from the transmission line, in this case the antenna "is matched to" the transmission line. Otherwise, the antenna reflects energy back down the line toward the transmitter. The incident waves from the transmitter and the reflected waves off the antenna combine to form standing waves. The ratio between the high and low voltage of the standing waves is

called the voltage standing wave ratio (VSWR). When the VSWR is 1, there are no standing waves on the line, and the antenna "matches" the line. As a rule, the VSWR should be less than 2 for modern solid-state transmitters. To avoid standing waves on the transmission line, the length of the antenna must be adjusted carefully so that the antenna presents a pure resistance input impedance equal to the characteristic impedance of the transmission line. A $\lambda/2$ dipole can operate with low VSWR in a narrow frequency range (±3%), called the operating frequency bandwidth.

The usual input impedance goal of HF transmitting antenna design is to minimize the VSWR over the operating frequency bandwidth. Modern solid-state transmitters require low VSWR to deliver maximum output power, cannot accept a VSWR of more than 3:1 and, will begin "shut down" and operate at insufficiently low output power for a VSWR > 2.

For operation at specific discrete frequencies, instead of using separate $\lambda/2$ dipoles, it may be preferable to use a single antenna structure able to operate at all the assigned frequencies. This can be achieved simply by "stacking", in parallel, center-fed $\lambda/2$ dipoles of different lengths connected to the same transmission line. The length of each $\lambda/2$ dipole corresponds to one of the desired operating frequencies. The dipole designed for that frequency is resonant and accepts and radiates the energy from the transmitter while the other dipoles reject the signal. An

antenna consisting of a group of parallel center-fed $\lambda/2$ dipoles and connected to the same transmission line so that it can operate efficiently at several distinct frequencies is called a multiband dipole [Ref. 5]. Actually, the Multiband Dipole Antenna can operate at frequencies within the bandwidth limits of each dipole. The $\lambda/2$ resonant length of any one dipole in the presence of the others is not the same as for a dipole by itself, due to mutual coupling effects. The dipoles should be separated as far from each other as practical to minimize coupling effects [Ref. 6].

III. GROUND MEASUREMENTS

Because of the importance of the electrical constants of the ground beneath antenna systems, as was described in Section 1 of Chapter II, these characteristics were determined accurately at the geographic location where the antenna was to be installed.

A. DESCRIPTION OF THE METHOD

1. Introduction

The Eyring Ground Measurement Probe System (P/N 200-4326) was used to measure the ground constants at the locations where the antenna was to be installed. The method employed utilizes software to derive the ground constants of soil under test by comparing the feed point impedance of a monopole probe radiating in air to its impedance when it is immersed in the soil beneath the antenna. This approach was inspired by the published work of Longmire and Smith, King, Smith and Norgard [Ref 7] as part of the Hardened Antenna Technology Program of the U.S.Air Force. The hardware design and analysis software were developed by the Communications Systems Division of Eyring, Inc.

2. Ground probe system

The probe basically is an electrically small monopole with a square ground plane. The monopole is robustly constructed so that it can be driven into the ground. Five different lengths of probes are used; 7", 13", 19", 25" and 31" long. A Hewlett-Packard HP-3577A Network Analyzer operates over a frequency range of 100 KHz to 200 MHz and connects to a coaxial line connected to each probe when it has been inserted into the ground. A complete ground probe measurement system is shown in Figure 4.

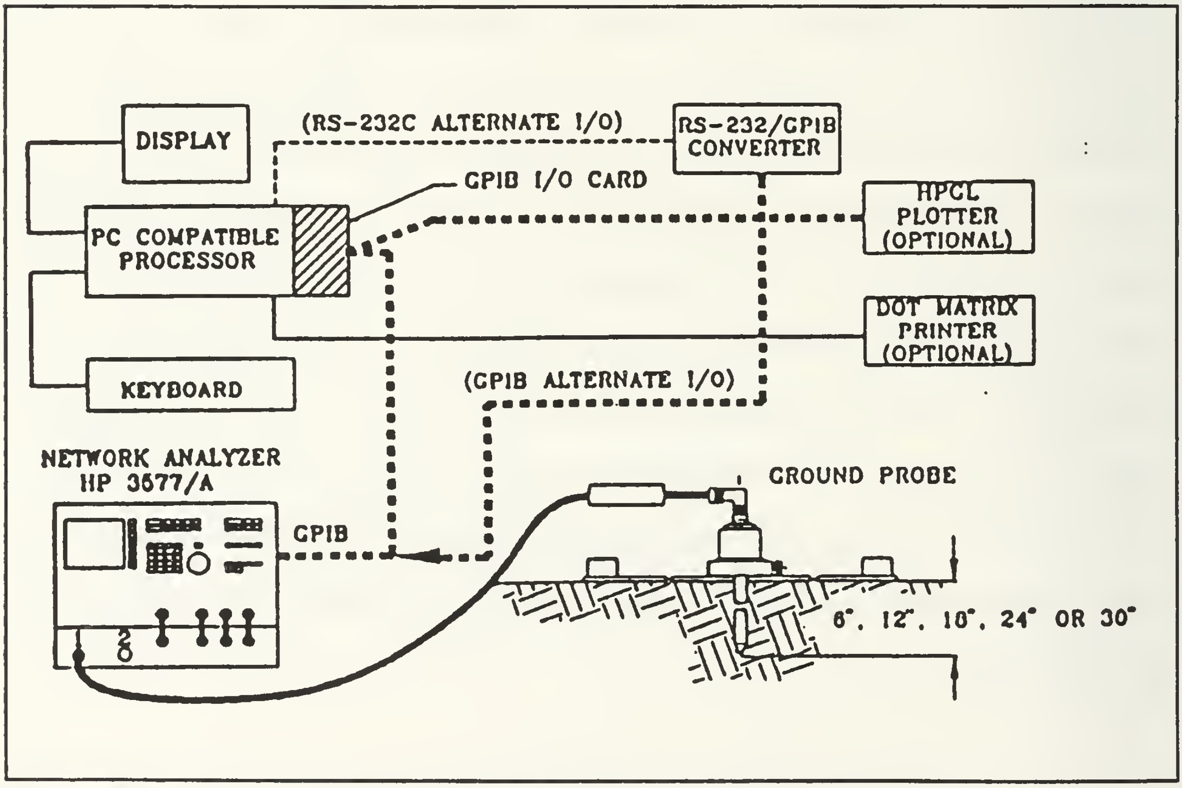

Figure 4: The ground probe measuring system [Ref 7].

B. MEASURED GROUND CONSTANTS

Using the Eyring Ground Measurement Probe System the ground constants of the NPS Beach area were determined. Three sets of measurements were made in the vicinity of the antenna site near the proposed locations for the Multiband Dipole Antenna supporting poles.

The data from the measurements is listed in Appendix A. By averaging the measurements of the five probes at each location, the average conductivity and permittivity vs frequency was obtained and is plotted in Figures 5 and 6. The three curves for the frequencies of interest were close together, indicating that the ground constants for each location are nearly the same. The ground constants used in the NEC analysis are the average of the three curves of the Figures 5 and 6 and are plotted in Figure 7.

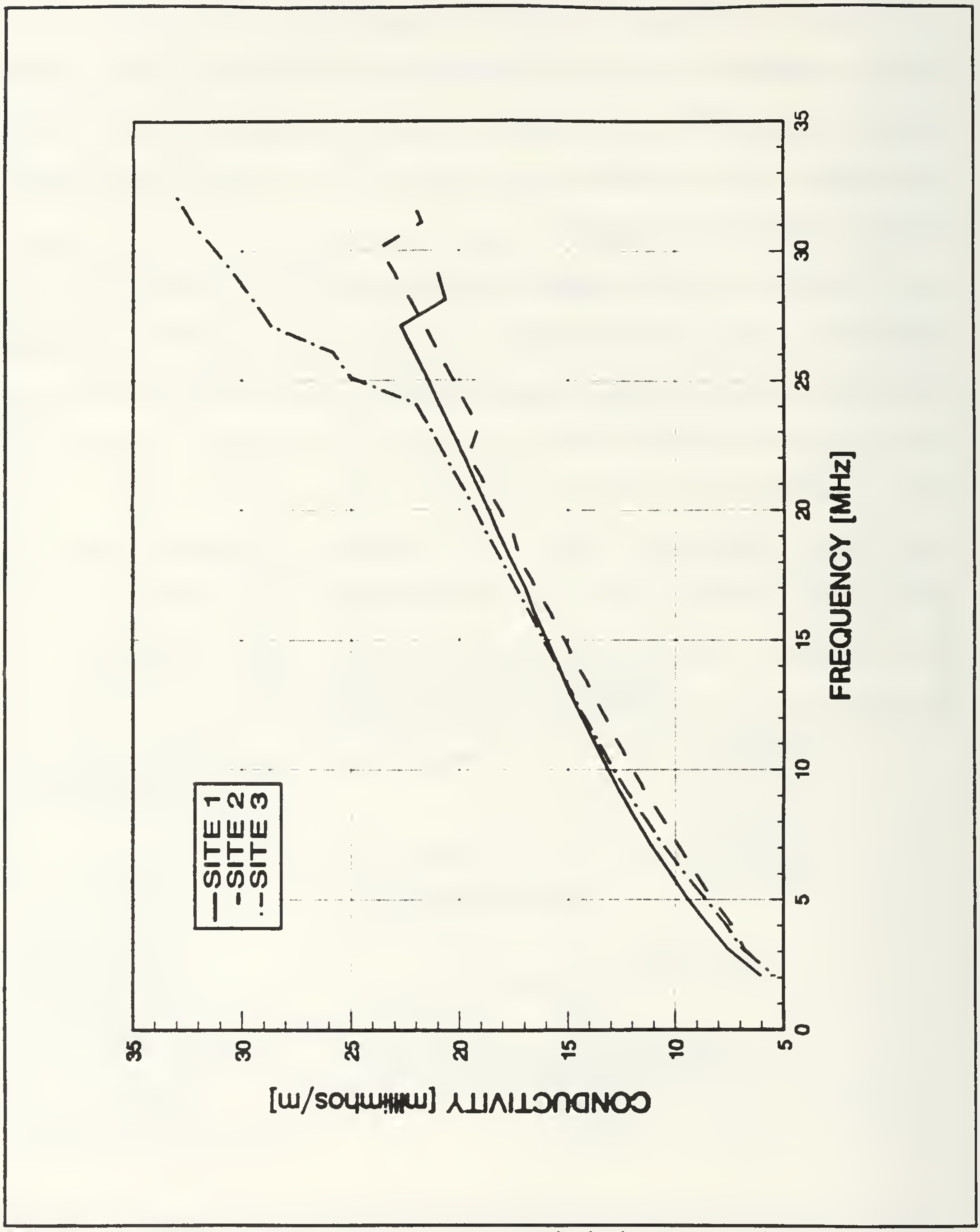

Figure 5: Average measured conductivities for sites 1,2 and 3 of the NPS Beach site.

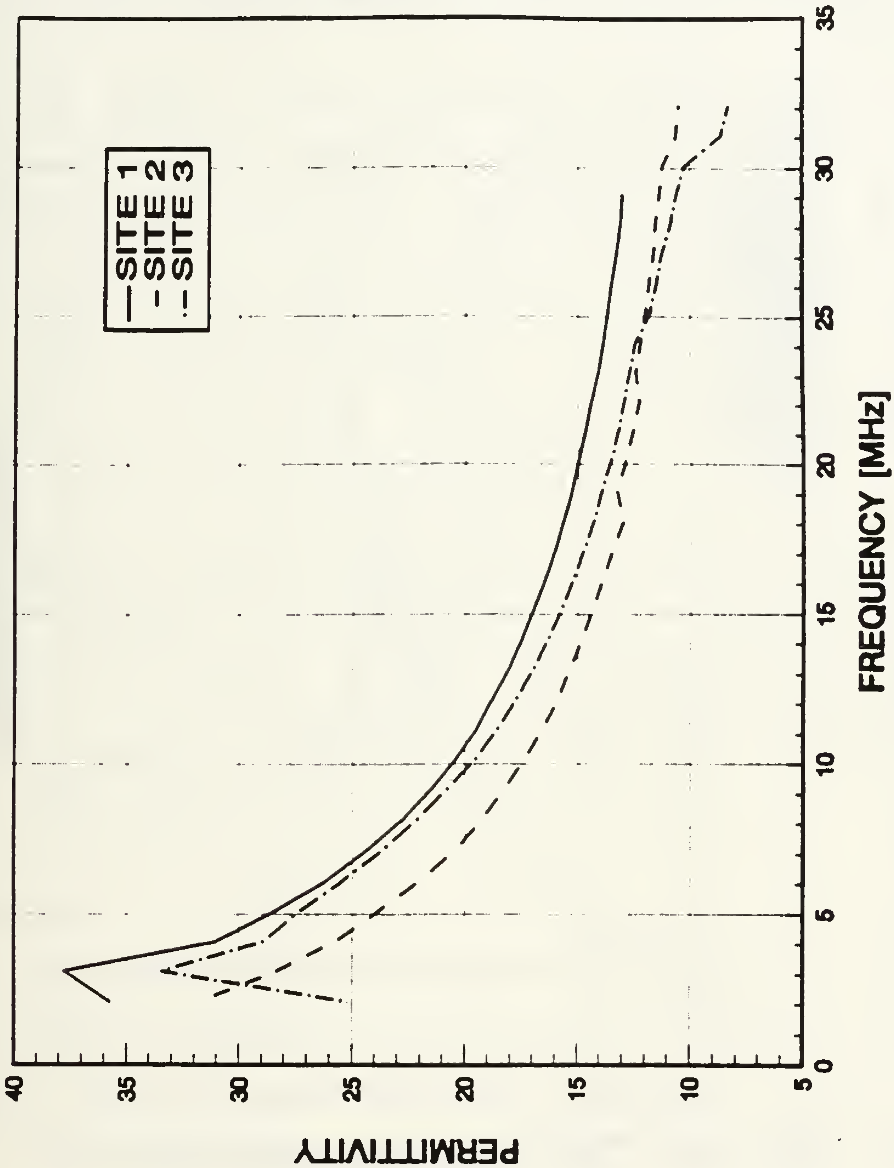

Figure 6: Average measured permittivities for sites 1, 2 and 3 of the NPS Beach site.

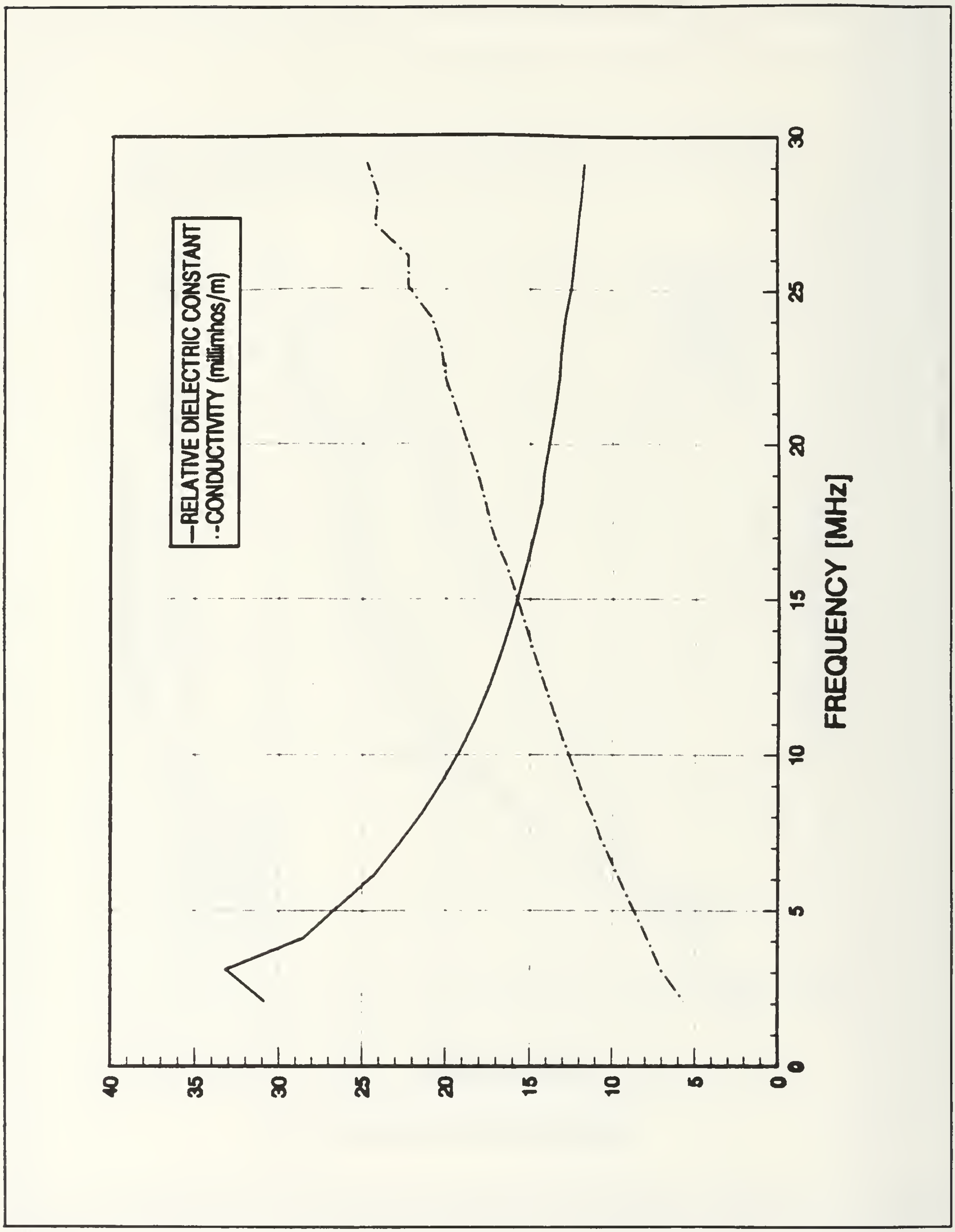

Figure 7: Average measured ground constants for the NPS Beach site.

IV. MULTIBAND DIPOLE DESIGN AND CONSTRUCTION

The $\lambda/2$ dipole is well-suited for skywave communications at HF frequencies for communication paths of relatively short distances (< 1000 Km). For this Near Vertical Incidence Skywave (NVIS) application, take off angles are between 30° and 90°. The radiation patterns in Figure 2, show that the horizontal dipole provides illumination of the ionosphere at angles more than 30° above the horizon.

Since there are three assigned frequencies, either three individual dipoles or one Multiband Dipole Antenna is needed. The Multiband Dipole Antenna was selected as the more practical antenna for PENEX use, using less real estate and support structure.

A. DESIGN

The Multiband dipole antenna must operate at 5.6, 11.0 and 16.8 MHz. According to the theory [Ref. 5], the antenna should be constructed of three elements of $\lambda/2$ length corresponding to each frequency. For low input VSWR the individual dipole antennas should be approximately 5% less than $\lambda/2$ long. The length of each dipole was found as shown in Table 1 and used to develop the initial model for NEC. The optimum length of each dipole, as shown in Table 1, was

Table 1: Dipole lengths of the antenna.

FREQUENCY [MHz]	λ/2 [m] / [ft]	0.95·λ/2 [m] / [ft]	OPTIMUM LENGTH [m] / [ft]
5.6	26.8 / 87.9	25.5 / 83.5	24.7 / 81.0
11.0	13.6 / 44.8	12.9 / 42.5	13.0 / 42.8
16.8	8.93 / 29.3	8.47 / 27.8	8.53 / 28.0

determined by trial and error, and by calculating the VSWRs based on the input impedances from NEC. The longest dipole (lowest frequency) was placed at the top of the support poles and the shortest at a lowest level to provide maximum height for the low frequency dipole. The three elements were cut at the center in order to feed them symmetrically with a balun. In order to minimize the mutual coupling between elements at the feed point region, it was decided to separate the element by spacing the ends of the first (top) and third (bottom) elements away from the ends of the second (center) element. The center of the first and the third elements are spaced one foot vertically from the center of the second element. The first and third element form an elevation angle of 11.21° and -11.21° with the second one. The diameter of the elements was controlled by the 1/16" copper wire used for construction.

The near optimum position of the antenna with respect to ground was determined to be 40 feet at the center with the

ends of the upper dipole elements being about 10 feet higher. The average height for the first element is 45 feet, corresponding to about $\lambda/4$ which should produce a radiation pattern of B and I in Figure 2. The height of the second element is 39 feet, which corresponds to 0.43λ, so a radiation pattern is expected somewhere between C and D and about J of Figure 2. For the third element, the average height was 35 feet which corresponds to about $5/8\ \lambda$, with expected radiation patterns of E and between J and K of Figure 2. These expected radiation patterns are well suited to the PENEX communication link.

The antenna was fed symmetrically at the center of the lower element. The dipoles are electrically connected in parallel with 2'x 1.5"x 0.021" copper strips in order to reduce the inductance of these feed line sections (Figure 8). The antenna is fed from a coaxial transmission line of 50 Ohms characteristic impedance. To minimize the effects of coupling between the dipoles and the coax, the line should be perpendicular to the axis of the antenna, in the same vertical plane containing the dipoles. The antenna is a balanced structure connected to an unbalanced transmission line. In an unbalanced system, the outer conductor and one arm of the dipole will be at a different potential level with respect to ground than that of the center conductor of the coaxial line and the other arm of the dipole. This causes a undesired modification of the radiation pattern of the antenna as

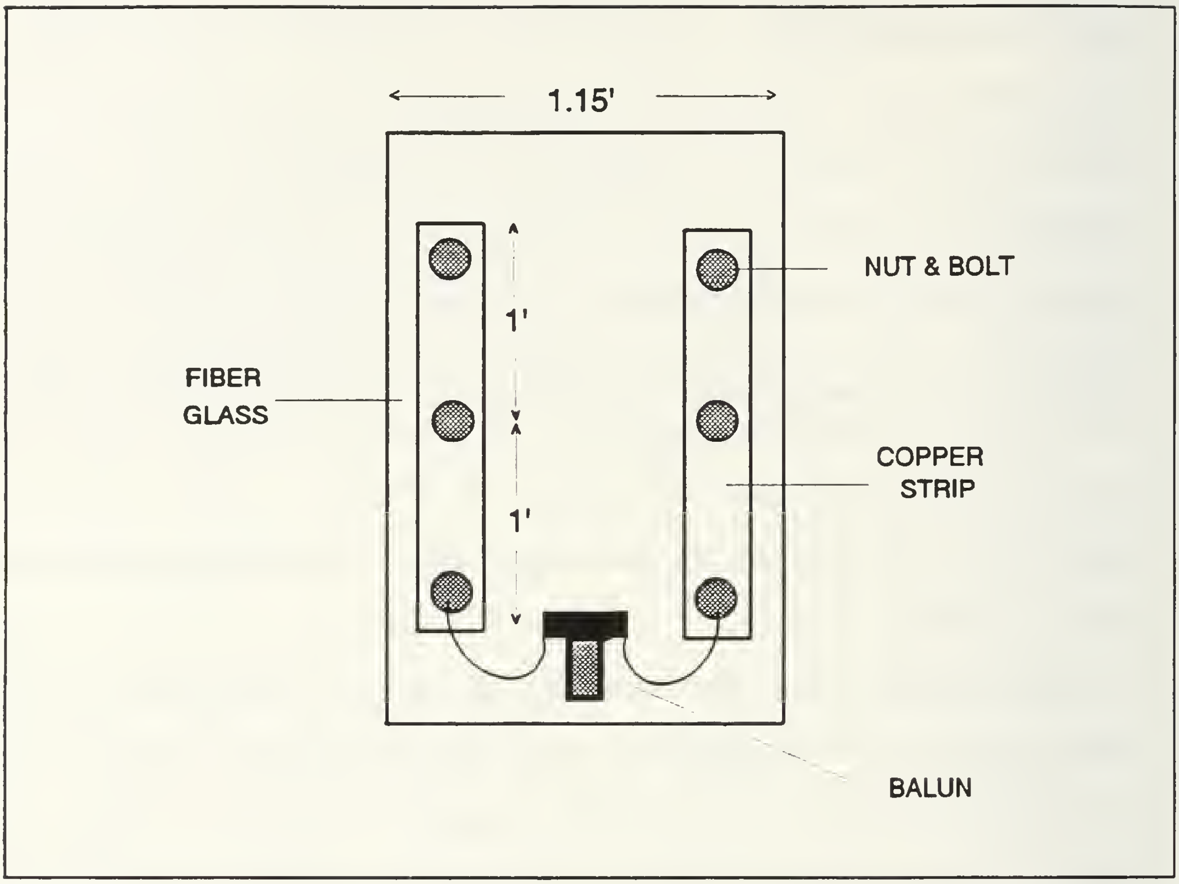

Figure 8: Feed system details for Multiband dipole antenna.

current on the inner surface of the shield will flow, in part, down the outside of the shield. The radiation pattern of the dipole will be distorted if this condition exists. To suppress the unbalanced shield current, it is necessary to use a device called a balun[1] to convert the unbalanced feed system to a balanced system [Ref. 8].

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[1]The word balun is derived from the word combination balanced-to-unbalanced.

B. CONSTRUCTION

Each dipole of the antenna was constructed of two pieces of wire, each being half optimum length, as prescribed in the design. A 1.15' x 3' x 1" board of sythane (bakelite and cloth laminate) was used to support, separate and insulate the three 1/16" diameter wire dipoles. The two copper strips were connected to the center of each of the dipoles and were mounted on the board using copper hardware. The balun was also secured to the board. The ends of the dipoles were connected via insulators to non-conducting ropes of 1/4" diameter and then were fastened to the supporting antenna poles, as shown in Figure 9.

Three wooden poles of 1' diameter and a height of 50' were used for support. The poles were placed at the NPS beach, 46' apart and along a bearing angle broadside to the San Diego direction. The board on the middle pole was elevated to a height of 40' from the ground. The ends of the ropes supporting the lower, middle and upper dipole were attached at heights of 30', 40' and 50' respectively from the ground on the outermost poles, as shown in Figure 10.

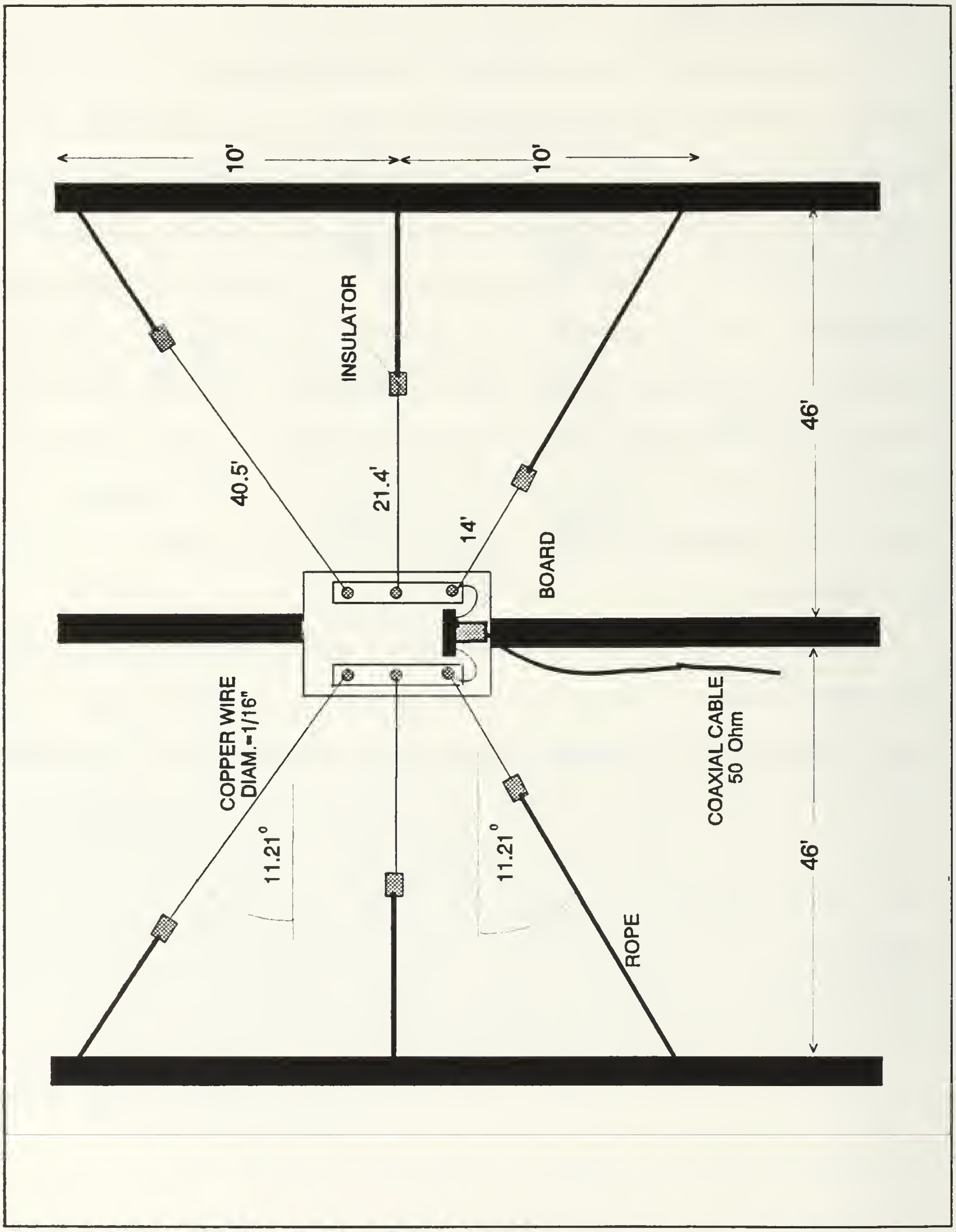


Figure 9: Multiband Dipole Antenna

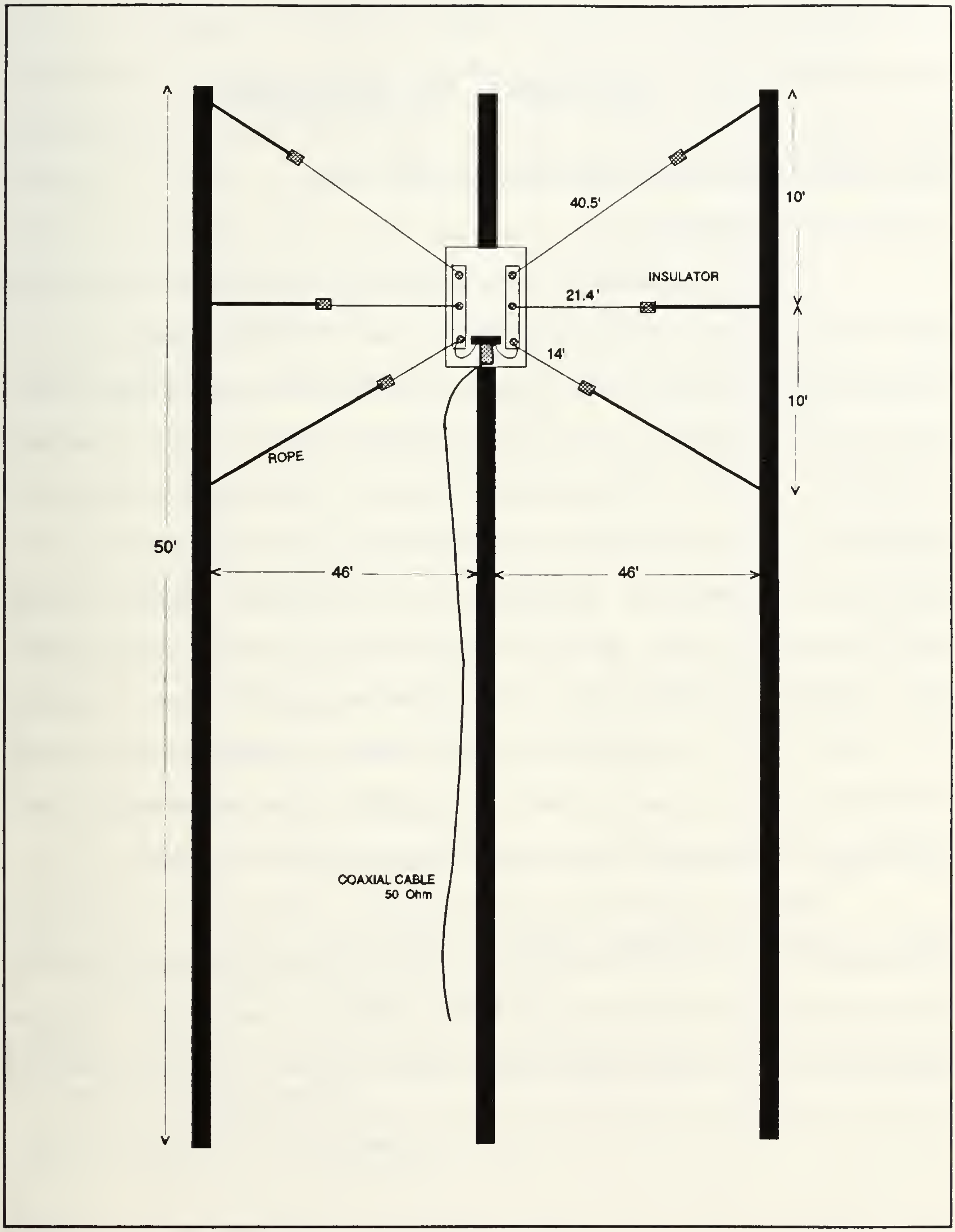


Figure 10: Multiband Dipole Antenna

V. NEC ANALYSIS AND MEASUREMENTS

A. THE NUMERICAL ELECTROMAGNETICS CODE

1. Description

Computer modeling of antennas which started in the late 1960's has become a powerful and widely used tool for antenna design. The Numerical Electromagnetics Code (NEC)-Method of Moments is a state-of-the-art antenna analysis computer program and has become one of the most widely used codes for modeling wire antennas. NEC was developed by the Lawrence Livermore National Laboratories under joint sponsorship of the Naval Ocean Systems Center and the Air Force Weapons Laboratory. Two versions of NEC are currently in use, NEC-2 and NEC-3. The only difference in the capabilities of these codes is that NEC-3 can model wires that penetrate the earth or are buried under the ground.

NEC is based on the numerical solution of integral equations (IE) for currents induced on a thin-wire structure from voltage sources or incident plane waves. NEC requires fewer of the simplifying assumptions used by other methods and is the most widely used thin-wire antenna modeling code.

A model may include lumped element loading, perfect or imperfect conductors, non-radiating networks and transmissions lines. The output includes near or far zone electric and magnetic fields, total radiation power and patterns, input power, currents and charge density, power gain or directive gain, and maximum coupling between antennas.

The numerical solution employs a matrix equation generated by the method of moments, whose order increases as the size of structure increases, relative to wavelength.

2. Wire antenna modeling guidelines

In order to model a wire in NEC, the wire must be divided into segments. A wire segment is determined by two parameters: the coordinates of the two end points and its radius. For the segmentation of a wire modeling in NEC, the following guidelines should be followed:

- Segments may not overlap.
- To connect segments ends, identical coordinates should be used.
- There is no connection between segments ends if the distance between them is greater than about 10^{-3} times the length of the shortest segment .
- The end of one wire should be connected at the junction of two segments of an other wire not at the any other mid-point of a segment.
- The length Δ of segments should be $0.1\lambda \leq \Delta \leq 0.001\lambda$ for each corresponding frequency.
- For modeling near multiple wire junctions or near feed points or other critical regions of an antenna, the segment length Δ should be 0.05λ or less.

- The changes in length between two adjacent connected wires should not be greater than twice; otherwise, tapered segment lengths should be used.
- The changes in radius between two adjacent connected wires cannot be greater than twice or the accuracy is reduced [Ref. 9].

B. MULTIBAND DIPOLE NUMERICAL MODELS

1. Geometry

From the design in Chapter III and the wire modeling guidelines in section A, a multiband dipole model was developed. Symmetry about the z-axis was used to reduce computational resources. The model was placed in the z-y plane. After setting wire segment lengths to $\Delta=0.02\lambda$, the number of segments, and the ratio R for the tapered segment lengths was found for each operating frequency, as shown in the Tables 2, 3, and 4. The ratios Δ/λ and Δ/α verify

Table 2: Segmentation of Multiband dipole NEC model for 5.6 MHz, $\Delta=0.02\lambda=1.07$m.

# OF SEGMENTS	Δ	R	Δ/λ	Δ/α
24	1.029	1.059	0.0192	1286.2
12	1.083	1.129	0.0202	1353.8
8	1.038	1.25	0.0194	1297.5

compliance with the segmentation NEC modeling guidelines. The radius α of a wire segment was 1/32"≈0.8mm which is within the NEC guidelines.

Table 3: Segmentation of Multiband dipole NEC model for 11 MHz, $\Delta=0.02\lambda=0.54$m.

# OF SEGMENTS	Δ	R	Δ/λ	Δ/α
46	0.537	1.018	0.0197	671.2
24	0.542	1.036	0.0199	677.5
16	0.519	1.086	0.019	648.8

Table 4: Segmentation of Multiband dipole NEC model for 16.8 MHz, $\Delta=0.02\lambda=0.35$m.

# OF SEGMENTS	Δ	R	Δ/λ	Δ/α
68	0.363	1.0045	0.02	453.7
36	0.361	1.0085	0.02	451.2
22	0.377	1.049	0.021	471.2

2. Program control

The multiband dipole model was fed symmetrically with 1 and -1 Volt at the center of the lower element of the antenna. The measured electrical constants of the NPS Beach site in Table 5, were taken from the Figure 7, for the desired operating frequencies and were used in NEC analysis.

Table 5: Measured electrical constants of the NPS Beach site.

FREQUENCY [MHz]	RELATIVE PERMITTIVITY	CONDUCTIVITY [mS/m]
5.6	25.54	9.25
11.0	18.32	13.33
16.8	14.65	16.82

Because the Multiband Dipole Antenna will be installed in Cape Wales, AK, its performance operating over tundra was modeled. Due to the severe weather conditions of Cape Wales, the electric constants vary with the seasons. Typical ground constants of wet, dry and frozen tundra are tabulated in Table 6.

Table 6: Typical ground constants for Arctic tundra.

FREQUENCY [MHz]	CONDUCTIVITY [mS/m]			RELATIVE PERMITTIVITY		
	WET	DRY	FROZEN	WET	DRY	FROZEN
5.6	17	5.5	1.7	55	20	12
11.0	18	6.2	2.6	40	16	8.7
16.8	21	6.8	3.0	33	11	7

In addition to the NPS Beach site and Arctic tundra the antenna was modeled over three generic grounds:

- Fair ground: conductivity=5 [mS/m], permittivity=12,
- Average ground: conductivity=3 [mS/m], permittivity=10,
- Poor ground: conductivity=1 [mS/m], permittivity=5.

The PROPHET system, which is a collection of computer simulation models developed to support tactical use of the HF band (2-32 MHz), was used to determine the incident wave angles at the ionosphere for a communication link between Monterey and San Diego. From PROPHET, the rays that reach the destination must take off with elevation angles as shown in Table 7. Radiation patterns at these elevation angles were calculated using NEC.

Table 7: Desired elevation angles for radiation patterns.

FREQUENCY [MHz]	RANGE OF ELEV. ANGLES	STEP SIZE
5.6	35°-60°	5°
11.0	5°-50°	5°
16.8	5°-16°	5° & 6°

C. NEC RESULTS

Based on the above NEC Multiband dipole model, the data sets illustrated in Appendix B were created. Using these data sets, input impedance and gain were calculated by NEC and tabulated in Tables 8-14. From calculated input impedance, VSWR was computed by [Ref. 10]:

$$VSWR = \frac{1+|\Gamma_L|}{1-|\Gamma_L|} , \tag{5}$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} , \tag{6}$$

where:

Γ_L = reflection coefficient,

Z_L = input impedance of the antenna, and

Z_0 = characteristic impedance of the transmission line.

Table 8: NEC performance predictions of the Multiband Dipole Antenna at the NPS Beach site.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	65.12 - j3.5	6.5	1.31
11.0	54.48 + j4.48	6.67	1.13
16.8	34.46 + j3.1	7.38	1.46

Table 9: NEC performance predictions of the Multiband Dipole Antenna over wet tundra.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	65.18 - j1.56	6.78	1.3
11.0	55.54 + j4.04	6.73	1.14
16.8	34.08 + j2.4	7.55	1.47

Table 10: NEC performance predictions of the Multiband Dipole Antenna over dry tundra.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	64.4 - j4.72	6.29	1.3
11.0	54.34 + j5.6	6.46	1.14
16.8	35.46 + j3.14	7.03	1.42

Table 11: NEC performance predictions of the Multiband Dipole Antenna over frozen tundra.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	62.48 - j7.14	5.82	1.29
11.0	53.48 + j7.14	6.14	1.16
16.8	36.44 + j3.24	6.67	1.38

Table 12: NEC performance predictions of the Multiband Dipole Antenna over average ground.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	64.0 - j7.34	5.9	1.32
11.0	53.72 + j6.84	6.2	1.16
16.8	36.0 + j2.86	6.84	1.4

Table 13: NEC performance predictions of the Multiband Dipole Antenna over fair ground.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	64.98 - j5.96	6.15	1.33
11.0	53.86 + j6.04	6.37	1.15
16.8	35.6 + j2.88	7.0	1.41

Table 14: NEC performance predictions of the Multiband Dipole Antenna over poor ground.

FREQUENCY [MHz]	INPUT IMPEDANCE [Ohm]	GAIN [dBi]	VSWR
5.6	61.9 - j11.0	5.2	1.34
11.0	52.74 + j8.9	5.69	1.2
16.8	37.32 + j3.08	6.29	1.35

Also, using the data sets of Appendix B, the azimuth radiation patterns at the elevation angles of Table 6 as well as elevation radiation patterns broadside (0° azimuth) and endfire (90° azimuth), were calculated by NEC for the antenna operating at NPS beach site, at each of the three assigned frequencies. These patterns are in of Appendix C. A sample of elevation patterns broadside to the antenna is shown in Figures 11, 12 and 13.

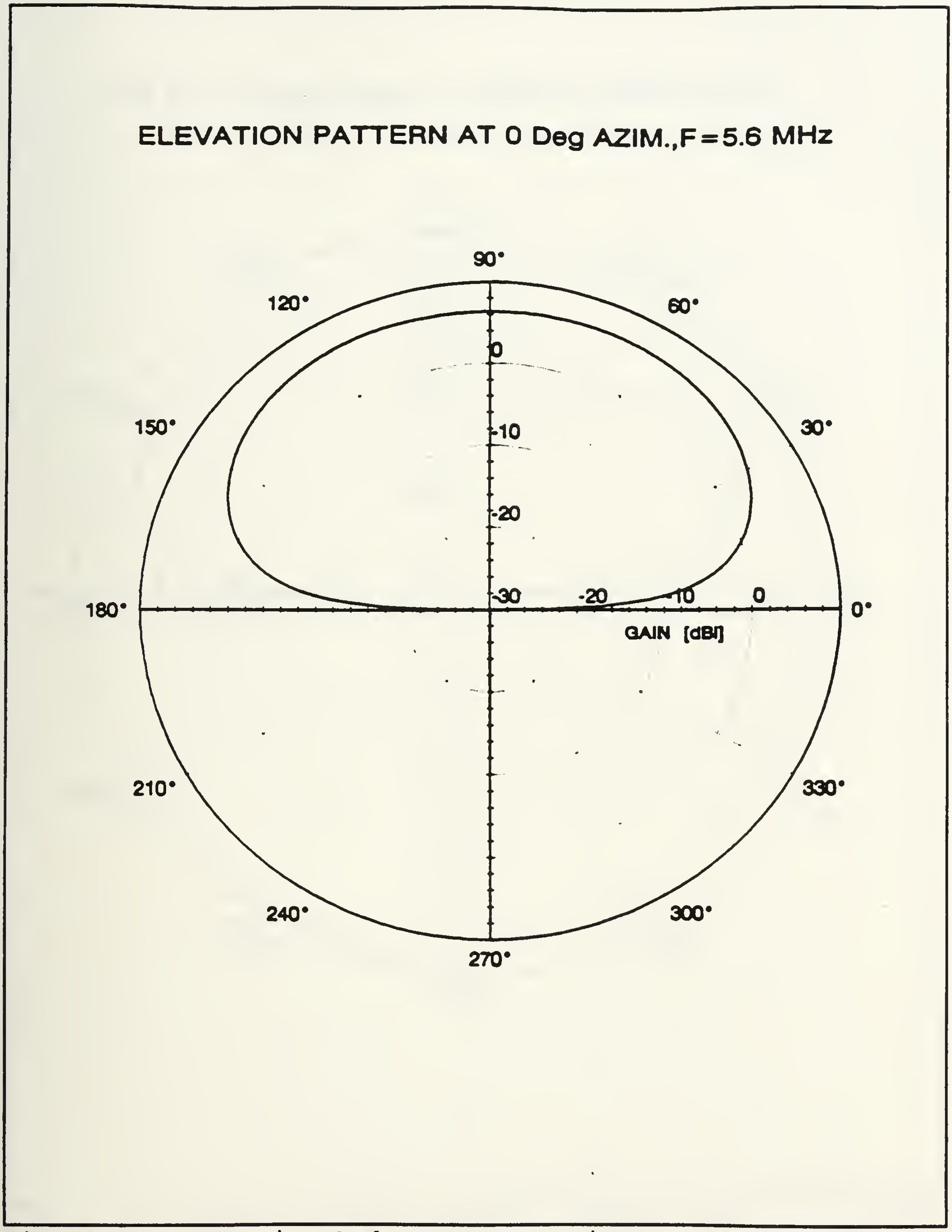


Figure 11: Elevation Rad. Pattern, Azim. 0°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

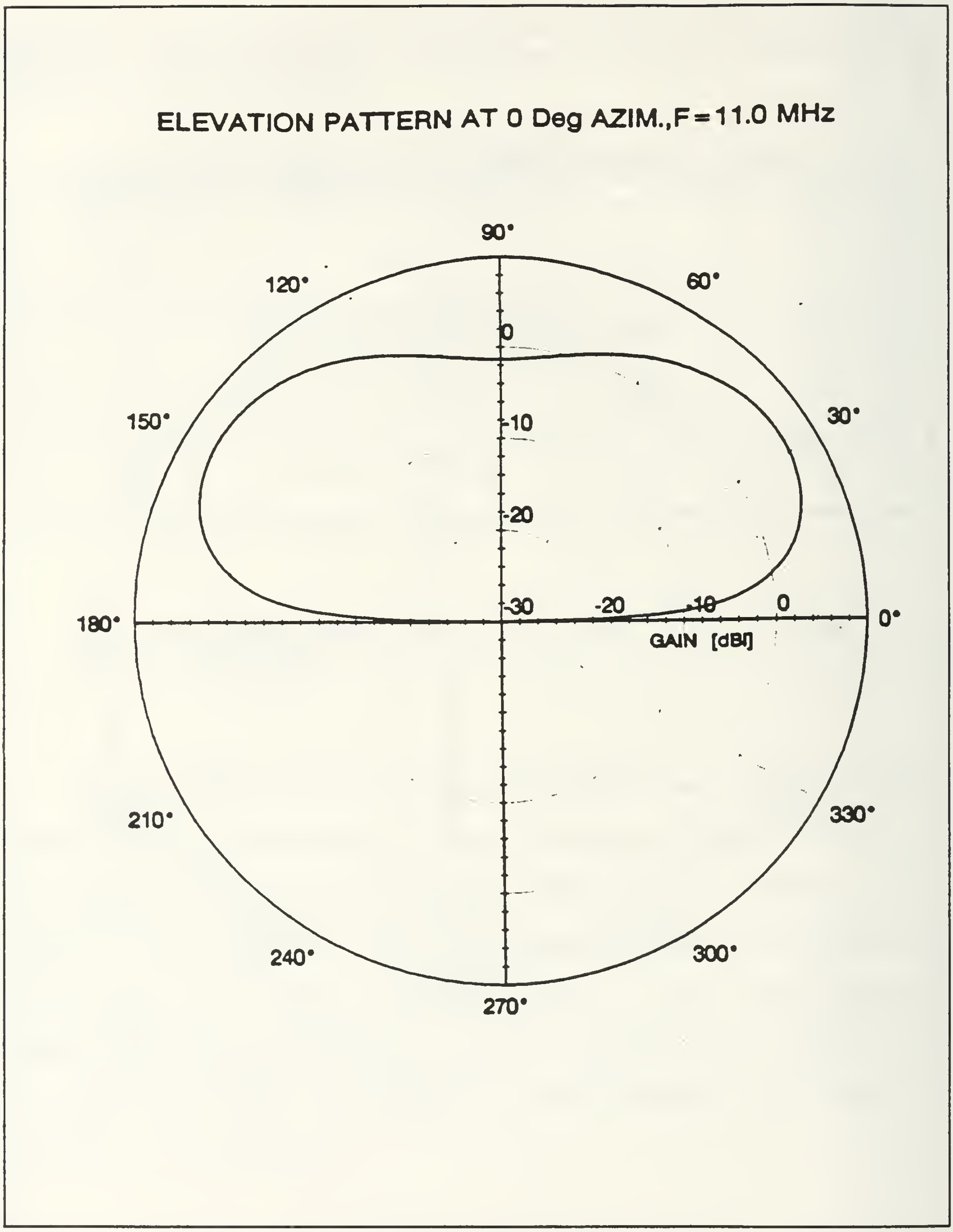


Figure 12: Elevation Rad. Pattern, Azim. 0°, f=11 MHz, Multiband Dipole Antenna at the NPS Beach site.

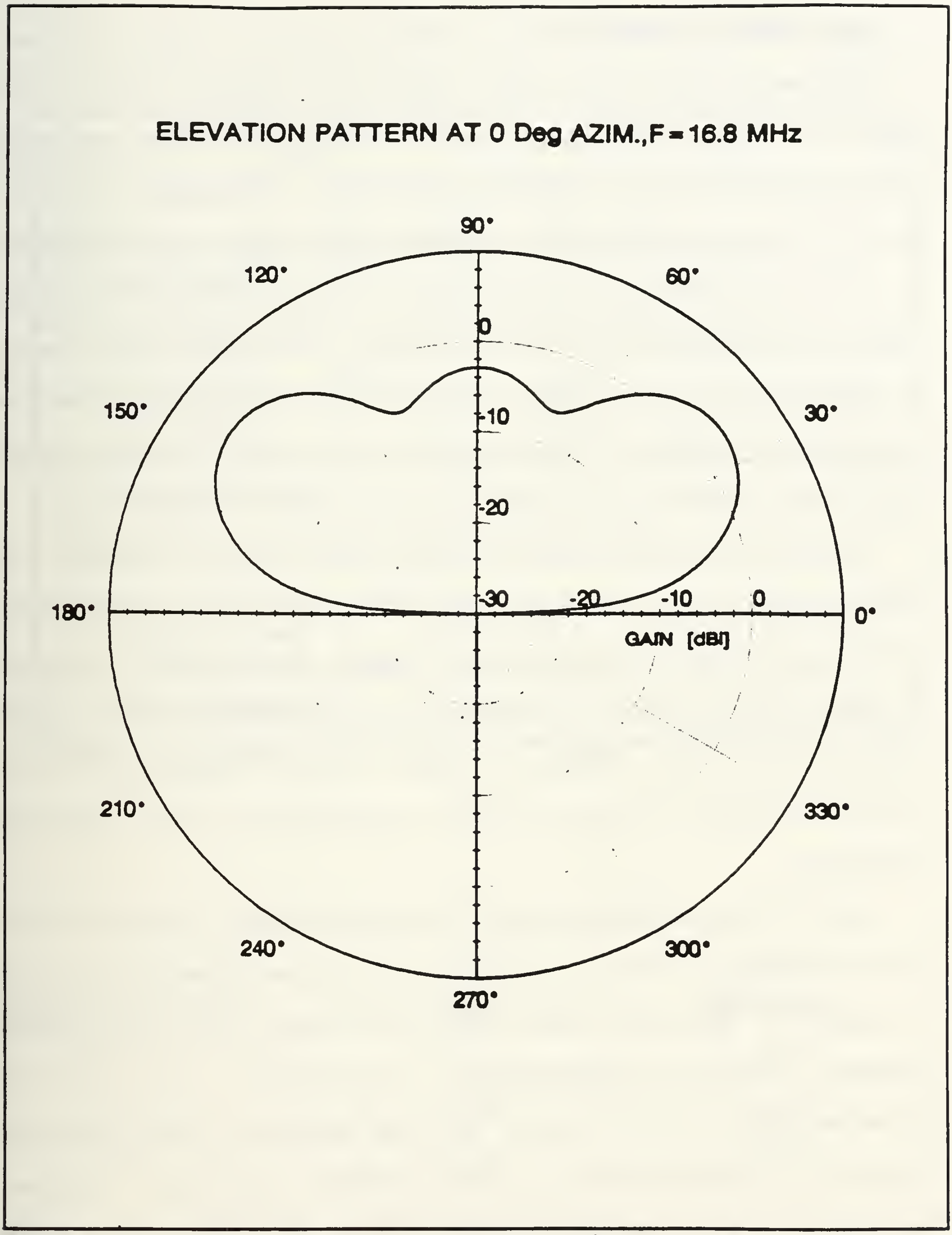


Figure 13: Elevation Rad. Pattern, Azim. 0°, f=16.8 MHz, Multiband Dipole Antenna at the NPS Beach site.

D. NEC RESULTS ANALYSIS

The multiband dipole NEC model was analyzed for a wide range of ground constants. The NEC calculated VSWRs and gains for each operating frequency with the different kinds of ground that the antenna was analyzed were tabulated in Tables 15 and 16. The means and variances of VSWRs and gains for each assigned frequency were listed under these tables. The value of VSWRs are low, less than 1.5. The small VSWRs variances and the values of Table 15 indicate that the ground constants have very small effect on the VSWR at all three frequencies.

The NEC calculated gains vary between 5.2 and 7.6 dBi. The gain figures drop gradually when the electrical constants of the ground beneath the antenna change from higher to lower values. The gains of the antenna are influenced by the ground constants but the change is small as is indicated by the values of Table 16 and the gain variances at each operating frequency.

The NEC calculated radiation patterns for the NPS Beach ground constants are in accordance with the theoretical ones in Figure 2. They also show that each dipole of the Multiband antenna operates independently. In general, the radiation patterns have one lobe which has low gain at lower elevation angles and good gain at the higher elevation angles. Therefore, the antenna is well suited for the short range ionospheric links of this design.

Table 15: NEC calculated VSWR of the Multiband Dipole Antenna.

GROUND	FREQUENCY [MHz]		
	5.6	11.0	16.8
NPS Beach	1.31	1.13	1.41
Wet tundra	1.3	1.14	1.47
Dry tundra	1.3	1.14	1.42
Frozen tundra	11.0	1.16	1.38
Fair ground	1.33	1.15	1.41
Average ground	1.32	1.16	1.4
Poor ground	1.34	1.2	1.35

FREQUENCY [MHz]	MEAN	VARIANCE
5.6	1.31	0.0003
11.0	1.15	0.0005
16.8	1.42	0.0024

Table 16: NEC calculated gains [dBi] of the Multiband Dipole Antenna.

GROUND	FREQUENCY [MHz]		
	5.6	11.0	16.8
NPS Beach	6.5	6.67	7.38
Wet tundra	6.78	6.73	7.55
Dry tundra	6.29	6.46	7.03
Frozen tundra	5.82	6.14	6.67
Fair ground	6.15	6.37	7.0
Average ground	5.9	6.2	6.84
Poor ground	5.2	5.69	6.29

FREQUENCY [MHz]	MEAN	VARIANCE
5.6	6.09	0.26
11.0	6.32	0.13
16.8	6.97	0.18

E. MULTIBAND DIPOLE MEASUREMENTS

In order to test the antenna design and measure the VSWR at the three assigned frequencies, it was connected to an HF transmitter via a 50 Ohm transmission line. The VSWR was read directly from the VSWR indicator of the transmitter, and tabulated in Table 17.

The data shows that the three points of lowest VSWR occur at or very close to the assigned operating frequencies and that the transmitter will operate well within the bandwidth of each $\lambda/2$-dipole.

Based on observed signal strengths at the San Diego receive site, the antenna appears to be performing very well. The transmitter modulation schemes consisted of a single-frequency carrier followed by teletype and digital data, with a total output power of 2.5 Watts at 5.6 MHz. Very strong and consistent signals with mean signal strength 19 [dB(μV)] were received. The output power was raised to 75 and 100 Watts at 5.6 and 11.0 MHz and the measured mean field strengths are tabulated in Table 18.

Table 17: Measured VSWR of the Multiband Dipole Antenna at the NPS Beach site.

FREQUENCY [MHz]	VSWR
5.41	2
5.49	1.5
5.6	1.3
5.69	1.5
5.80	2
10.55	2
10.67	1.5
10.84	1.25
11.00	1.4
11.04	1.5
11.19	2
16.55	2
16.66	1.5
16.80	1.2
16.8[illegible]	1.15
17.1	1.5
17.31	2

Table 18: PENEX mean measured field strengths at San Diego receive site.

FREQUENCY [MHz]	POWER [W]	FIELD STRENGTH [dB(μV/m)]	DATE
5.6	2.5	6	8/28/92
5.6	75	10	10/2/92
11.0	100	19	10/2/92
5.6	75	7	10/4/92
5.6	75	6	10/7/92

F. COMPARISON OF NEC-CALCULATED AND MEASURED VALUES

Table 19 shows a comparison of the measured and NEC results for the VSWR at the NPS Beach site. The VSWR, is less than the design maximum of 1.5 for all three transmission frequencies.

Table 19: Measured and NEC-calculated VSWR of the Multiband Dipole Antenna at the NPS Beach site.

FREQUENCY [MHz]	NEC VSWR	MEASURED VSWR
5.6	1.31	1.3
11	1.13	1.4
16.8	1.46	1.2

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In this thesis the Multiband Dipole Antenna has been designed, analyzed, constructed and measured. The antenna was installed at the NPS beach where the ground constants were measured accurately. The PENEX transmitter chain was used with the antenna to establish the required link to San Diego.

The design of the antenna was based on $\lambda/2$ dipoles. A $\lambda/2$ dipole operates with low VSWR in a narrow operating frequency bandwidth. For the three assigned frequencies, which are separated by more than the bandwidth for each $\lambda/2$ dipole, three separate $\lambda/2$ dipoles would be required but the cost and size would be excessive for this application. A combined dipole structure would be inexpensive and have a low footprint. A Multiband Dipole Antenna is a combined dipole structure consisting of a group of parallel $\lambda/2$ dipoles connected to the same transmission line, that can operate at the several distinct frequencies without the degradation of mutual coupling effects. Therefore, the Multiband Dipole was selected as the most practical approach for the transmitting requirements of the PENEX project.

Initially, the length of each dipole was calculated, but the final length was determined by trial and error using NEC.

The correct dipole length resulted in low VSWR at the three assigned frequencies. The NEC-derived VSWR was verified by measurements.

The design of this Multiband Dipole Antenna differs from previous versions of the antenna in the feed system configuration used. The antenna was fed at the center of the lower element and the dipoles were connected with copper strips. In the Stanford Research Institute (SRI) versions the center dipole was fed and the dipoles were connected with wires fanned from the center point. The strips of the design reduce the feed point inductance without modifying the radiation pattern of the antenna.

The height of the antenna was chosen to obtain the correct radiation pattern take-off angles for the PENEX ionospheric communication link. The radiation patterns have one lobe with good gain at middle and high elevation angles, which is ideal for the short range ionospheric link from Monterey to San Diego. The ground constants did not influence the operation of the antenna substantially, because of the height of the antenna, as shown by NEC results and measured VSWR.

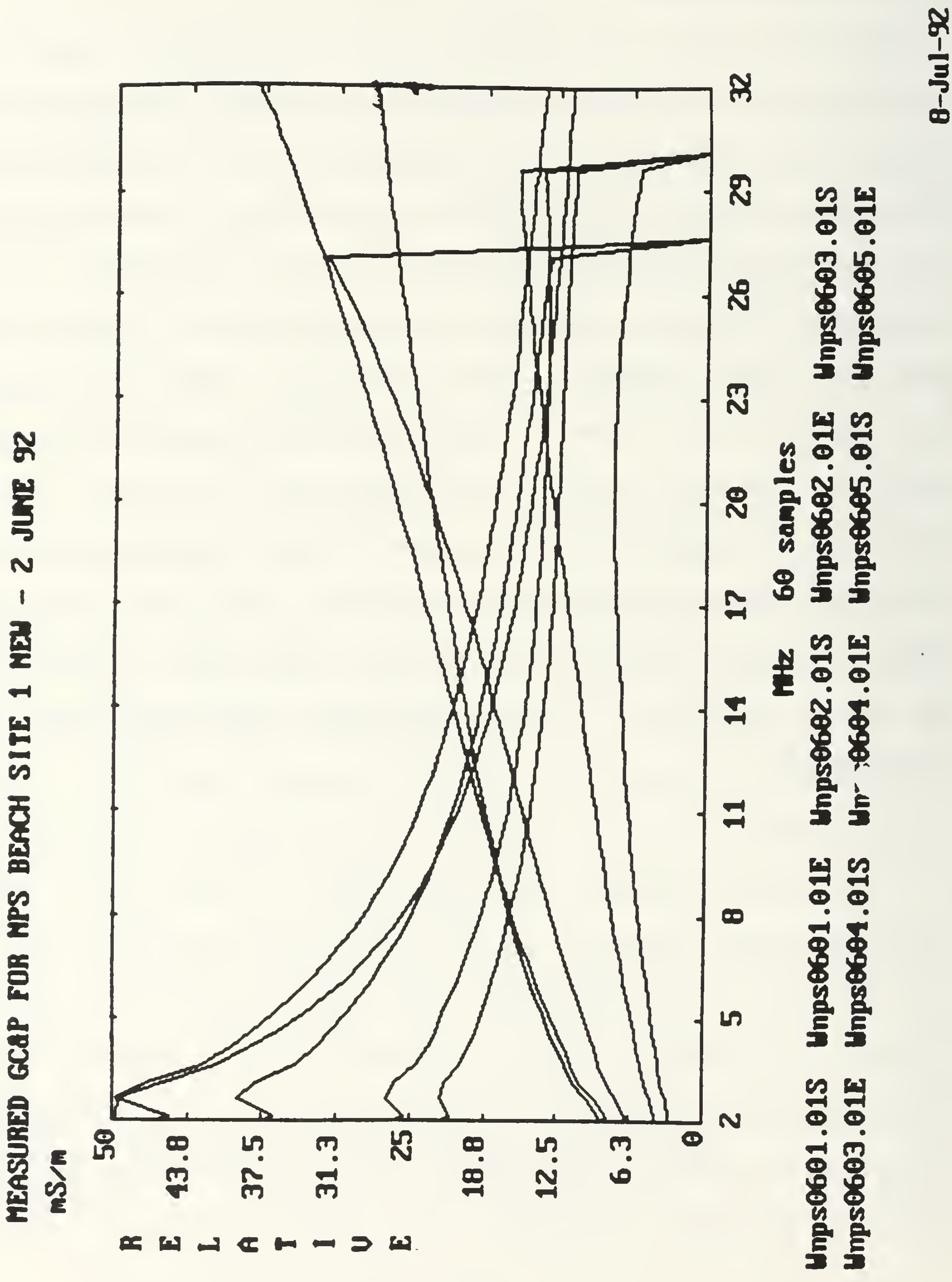
The Multiband Dipole Antenna is an easily constructed and low cost antenna and has a small footprint. It is insensitive to electrical ground characteristics, and with the correct resonant lengths of the dipoles, the antenna provides a good match to a transmitter on each frequency. Proper choice of the height of the antenna via numerical modeling provides

excellent radiation patterns for ionospheric communication links.

B. RECOMMENDATIONS

The Multiband Dipole Antenna was constructed for operation at NPS Beach Monterey, CA, where the weather conditions are usually mild. However, the antenna will be installed in Cape Wales, AK, where strong winds blow and the temperature is extremely low for several months of the year. Therefore, it is recommended that the antenna be constructed of more rugged materials. The strong winds may damage the antenna and also may blow the wires closer to each other so that detuning will occur. In order to reduce the effect of the winds on the wires, it is recommended the wires be hard-drawn copper and the plastic ropes be replaced with strong wire cable. The low temperature may fracture the antenna feed board used at the NPS beach, therefore, a heavy laminated fiberglass board is recommended.

APPENDIX A. EYRING GROUND MEASUREMENT PROBE SYSTEM OUTPUTS



Wnps0601.01E GNDNPS 7" Probe GND, Permittivity 22-Jun-92 10:46:56
Wnps0601.01S GNDNPS 7" Probe GND, Conductivity 22-Jun-92 10:46:56
Cutoff Frequency = 132.53 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	49.6	8.79	1.52	5.05	142.93	17.10
3.10	45.7	10.93	1.39	3.83	96.82	12.30
4.10	38.5	12.35	1.41	3.12	73.21	10.11
5.10	34.0	13.64	1.41	2.65	58.85	8.63
6.10	30.4	14.75	1.43	2.33	49.20	7.62
7.10	27.7	15.72	1.44	2.09	42.27	6.85
8.10	25.4	16.59	1.45	1.90	37.06	6.25
9.10	23.7	17.37	1.45	1.75	32.98	5.77
10.10	22.2	18.03	1.45	1.63	29.72	5.37
11.09	20.9	18.72	1.45	1.53	27.04	5.03
12.09	19.9	19.35	1.45	1.44	24.81	4.74
13.09	19.0	19.90	1.44	1.36	22.91	4.48
14.09	18.1	20.44	1.44	1.30	21.29	4.26
15.09	17.4	20.97	1.43	1.24	19.88	4.06
16.09	16.8	21.46	1.43	1.19	18.64	3.88
17.09	16.2	21.91	1.42	1.14	17.55	3.73
18.09	15.7	22.38	1.42	1.10	16.58	3.58
19.09	15.2	22.87	1.42	1.06	15.71	3.45
20.09	14.8	23.28	1.41	1.02	14.93	3.33
21.09	14.4	23.72	1.41	0.99	14.23	3.21
22.09	14.0	24.19	1.41	0.96	13.58	3.11
23.09	13.6	24.60	1.41	0.93	12.99	3.02
24.09	13.3	25.06	1.41	0.90	12.45	2.92
25.09	13.0	25.50	1.40	0.88	11.96	2.84
26.09	12.8	25.91	1.39	0.85	11.50	2.76
27.09	12.5	26.31	1.39	0.83	11.08	2.68
28.09	12.3	26.73	1.39	0.81	10.68	2.61
29.09	12.1	27.11	1.38	0.79	10.31	2.55
30.09	11.9	27.48	1.38	0.77	9.97	2.49
31.08	11.7	27.87	1.38	0.76	9.65	2.43
32.08	11.5	28.26	1.38	0.74	9.35	2.37

Wnps0602.01E GNDNPS 13" PROBE GND, Permittivity 22-Jun-92 10:53:
Wnps0602.01S GNDNPS 13" PROBE GND, Conductivity 22-Jun-92 10:53:
Cutoff Frequency = 40.08 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	45.3	8.20	1.55	5.20	142.93	17.81
3.10	47.1	10.45	1.29	4.00	96.82	12.31
4.10	40.2	11.75	1.28	3.28	73.21	10.08
5.10	36.6	13.07	1.26	2.81	58.85	8.52
6.10	33.4	14.27	1.26	2.46	49.20	7.45
7.10	30.9	15.39	1.26	2.19	42.27	6.66
8.10	28.8	16.40	1.27	1.99	37.06	6.04
9.10	27.0	17.34	1.27	1.82	32.98	5.55
10.10	25.5	18.20	1.27	1.69	29.72	5.15
11.09	24.3	19.03	1.27	1.57	27.04	4.80
12.09	23.2	19.89	1.28	1.47	24.81	4.50
13.09	22.3	20.69	1.28	1.39	22.91	4.24
14.09	21.4	21.47	1.28	1.31	21.29	4.02
15.09	20.7	22.25	1.28	1.24	19.88	3.82
16.09	20.0	23.06	1.29	1.18	18.64	3.64
17.09	19.4	23.86	1.29	1.13	17.55	3.47
18.09	18.8	24.64	1.30	1.07	16.58	3.33
19.09	18.3	25.46	1.31	1.03	15.71	3.19
20.09	17.8	26.31	1.32	0.98	14.93	3.07
21.09	17.4	27.15	1.33	0.94	14.23	2.96
22.09	17.0	28.02	1.34	0.90	13.58	2.85
23.09	16.5	28.93	1.36	0.87	12.99	2.76
24.09	16.2	29.81	1.37	0.83	12.45	2.66
25.09	15.9	30.75	1.39	0.80	11.96	2.58
26.09	15.6	31.73	1.41	0.77	11.50	2.50
27.09	15.3	32.68	1.42	0.74	11.08	2.42
28.09	15.0	33.77	1.44	0.71	10.68	2.35
29.09	14.7	34.83	1.47	0.69	10.31	2.29
30.09	14.4	35.92	1.49	0.66	9.97	2.22
31.08	14.0	36.92	1.52	0.64	9.65	2.17
32.08	13.8	38.19	1.55	0.62	9.35	2.11

Wnps0603.01E GNDNPS 19" PROBE GND, Permittivity 22-Jun-92 11:07:42
Wnps0603.01S GNDNPS 19" PROBE GND, Conductivity 22-Jun-92 11:07:42
Cutoff Frequency = 27.59 MHz

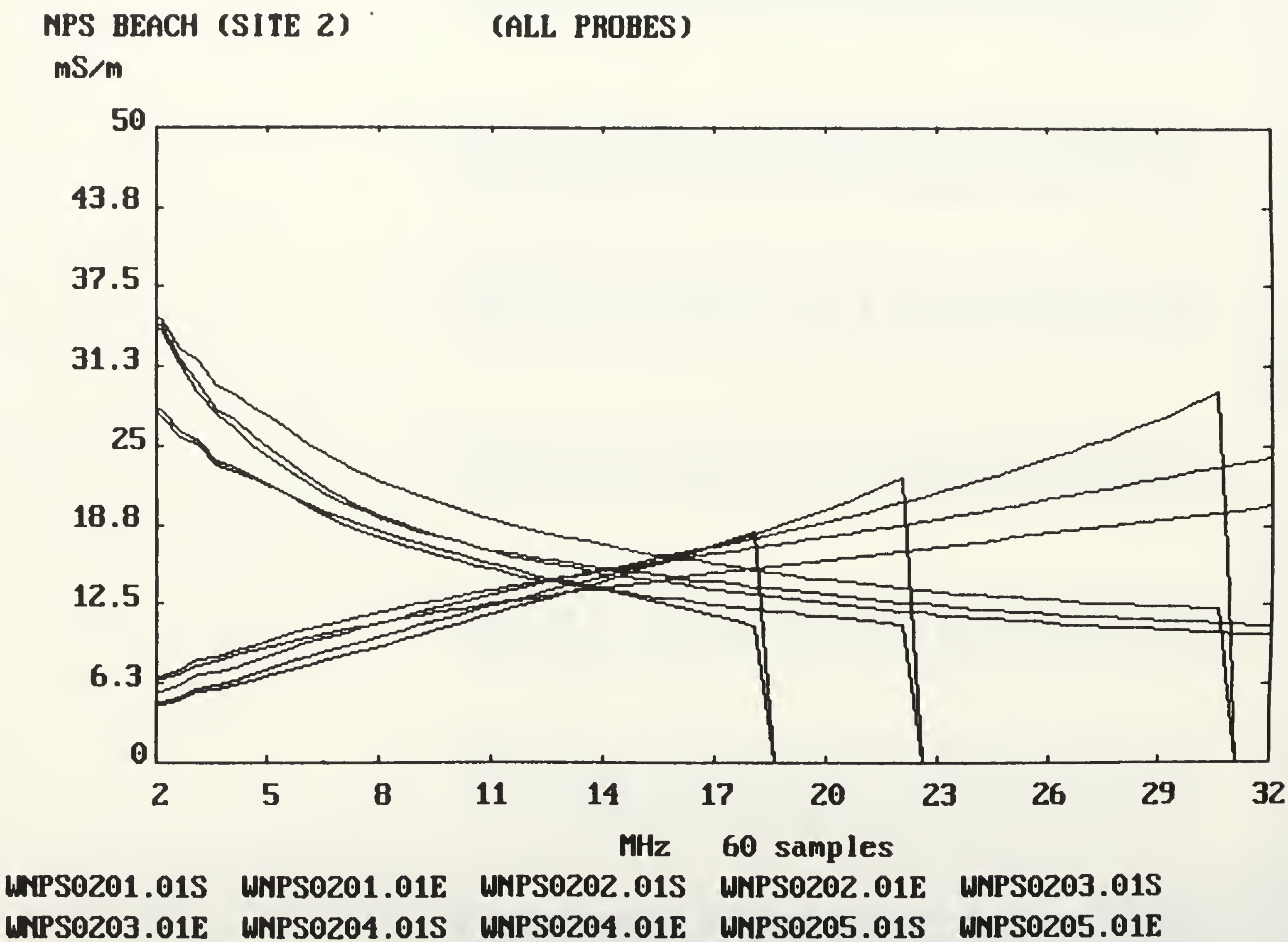
MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	36.6	6.52	1.53	5.86	142.93	19.89
3.10	38.0	8.15	1.24	4.58	96.82	13.78
4.10	32.9	9.18	1.22	3.77	73.21	11.23
5.10	30.4	10.21	1.18	3.24	58.85	9.45
6.10	28.2	11.17	1.17	2.85	49.20	8.22
7.10	26.4	12.13	1.17	2.53	42.27	7.31
8.10	24.8	13.00	1.16	2.29	37.06	6.61
9.10	23.5	13.90	1.17	2.09	32.98	6.04
10.10	22.3	14.69	1.17	1.93	29.72	5.58
11.09	21.4	15.49	1.17	1.79	27.04	5.19
12.09	20.5	16.31	1.18	1.66	24.81	4.85
13.09	19.7	17.12	1.19	1.56	22.91	4.56
14.09	19.1	17.91	1.20	1.47	21.29	4.31
15.09	18.4	18.74	1.21	1.38	19.88	4.08
16.09	17.9	19.59	1.23	1.30	18.64	3.88
17.09	17.3	20.51	1.24	1.23	17.55	3.70
18.09	16.9	21.43	1.26	1.16	16.58	3.54
19.09	16.4	22.35	1.28	1.10	15.71	3.39
20.09	16.0	23.34	1.31	1.05	14.93	3.25
21.09	15.5	24.42	1.34	0.99	14.23	3.12
22.09	15.2	25.50	1.37	0.94	13.58	3.00
23.09	14.8	26.68	1.40	0.89	12.99	2.89
24.09	14.4	27.97	1.45	0.85	12.45	2.79
25.09	14.1	29.28	1.49	0.81	11.96	2.69
26.09	13.7	30.73	1.54	0.76	11.50	2.61
27.09	13.3	32.32	1.62	0.72	11.08	2.52

Wnps0604.01E GNDNPS 25" PROBE GND, Permittivity 22-Jun-92 11:12:5
Wnps0604.01S GNDNPS 25" PROBE GND, Conductivity 22-Jun-92 11:12:5
Cutoff Frequency = 30.09 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	25.5	4.00	1.34	7.75	142.93	24.48
3.10	26.4	4.87	1.07	6.22	96.82	16.98
4.10	23.5	5.50	1.03	5.17	73.21	13.69
5.10	22.2	6.10	0.97	4.48	58.85	11.43
6.10	20.9	6.69	0.94	3.96	49.20	9.88
7.10	19.8	7.28	0.93	3.53	42.27	8.74
8.10	18.9	7.78	0.91	3.22	37.06	7.86
9.10	18.0	8.32	0.91	2.94	32.98	7.16
10.10	17.3	8.78	0.90	2.73	29.72	6.59
11.09	16.7	9.22	0.89	2.55	27.04	6.11
12.09	16.2	9.67	0.89	2.39	24.81	5.70
13.09	15.7	10.09	0.88	2.25	22.91	5.35
14.09	15.3	10.50	0.88	2.14	21.29	5.04
15.09	15.0	10.91	0.87	2.03	19.88	4.77
16.09	14.6	11.30	0.86	1.94	18.64	4.52
17.09	14.4	11.72	0.86	1.85	17.55	4.30
18.09	14.1	12.10	0.85	1.77	16.58	4.10
19.09	13.9	12.55	0.85	1.70	15.71	3.92
20.09	13.7	12.96	0.85	1.63	14.93	3.75
21.09	13.6	13.37	0.84	1.57	14.23	3.60
22.09	13.5	13.75	0.83	1.52	13.58	3.45
23.09	13.4	14.11	0.82	1.48	12.99	3.31
24.09	13.4	14.52	0.81	1.43	12.45	3.18
25.09	13.4	14.84	0.79	1.40	11.96	3.06
26.09	13.5	15.15	0.78	1.37	11.50	2.95
27.09	13.6	15.44	0.76	1.34	11.08	2.83
28.09	13.6	15.75	0.74	1.32	10.68	2.73
29.09	13.8	15.92	0.72	1.31	10.31	2.63

Wnps0605.01E GNDNPS 31" PROBE GND, Permittivity 22-Jun-92 11:20:17
Wnps0605.01S GNDNPS 31" PROBE GND, Conductivity 22-Jun-92 11:20:17
Cutoff Frequency = 30.09 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	21.6	2.87	1.14	9.65	142.93	27.41
3.10	22.0	3.45	0.91	7.83	96.82	19.04
4.10	20.0	3.93	0.86	6.51	73.21	15.21
5.10	18.9	4.37	0.82	5.65	58.85	12.66
6.10	17.9	4.78	0.79	5.01	49.20	10.91
7.10	17.1	5.17	0.77	4.52	42.27	9.62
8.10	16.4	5.54	0.75	4.12	37.06	8.63
9.10	15.8	5.87	0.74	3.81	32.98	7.84
10.10	15.2	6.17	0.72	3.55	29.72	7.20
11.09	14.8	6.44	0.71	3.34	27.04	6.67
12.09	14.4	6.68	0.69	3.17	24.81	6.22
13.09	14.0	6.89	0.68	3.03	22.91	5.83
14.09	13.7	7.10	0.66	2.90	21.29	5.49
15.09	13.4	7.27	0.65	2.80	19.88	5.19
16.09	13.2	7.43	0.63	2.71	18.64	4.92
17.09	12.9	7.55	0.61	2.64	17.55	4.68
18.09	12.8	7.66	0.60	2.58	16.58	4.46
19.09	12.6	7.74	0.58	2.53	15.71	4.26
20.09	12.5	7.78	0.56	2.50	14.93	4.08
21.09	12.4	7.77	0.54	2.48	14.23	3.92
22.09	12.2	7.73	0.51	2.48	13.58	3.77
23.09	12.1	7.61	0.49	2.50	12.99	3.63
24.09	12.0	7.46	0.46	2.53	12.45	3.51
25.09	11.9	7.24	0.44	2.59	11.96	3.39
26.09	11.8	6.99	0.41	2.66	11.50	3.29
27.09	11.6	6.68	0.38	2.76	11.08	3.19
28.09	11.4	6.35	0.36	2.87	10.68	3.11
29.09	11.2	5.99	0.33	3.01	10.31	3.04


NPS BEACH (SITE 2)
(ALL PROBES)
mS/m
50
43.8
37.5
31.3
25
18.8
12.5
6.3
0
2
5
8
11
14
17
20
23
26
29
32
MHz 60 samples
WNPS0201.01S WNPS0201.01E WNPS0202.01S WNPS0202.01E WNPS0203.01S
WNPS0203.01E WNPS0204.01S WNPS0204.01E WNPS0205.01S WNPS0205.01E

WNPS0101.01E GNDNPS 7" Probe GND, Permittivity 9-Jun-92 10:55:10
WNPS0101.01S GNDNPS 7" Probe GND, Conductivity 9-Jun-92 10:55:10
Cutoff Frequency = 126.54 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	45.6	8.07	1.52	5.27	142.93	17.84
3.10	39.5	9.68	1.42	4.04	96.82	13.17
4.10	34.2	10.72	1.37	3.37	73.21	10.77
5.10	31.1	11.64	1.32	2.93	58.85	9.16
6.10	28.7	12.48	1.28	2.61	49.20	8.02
7.10	26.8	13.27	1.25	2.36	42.27	7.16
8.10	25.3	13.98	1.23	2.17	37.06	6.48
9.10	24.0	14.67	1.21	2.01	32.98	5.94
10.10	23.0	15.30	1.18	1.88	29.72	5.49
11.09	22.0	15.95	1.17	1.76	27.04	5.11
12.09	21.2	16.51	1.16	1.67	24.81	4.79
13.09	20.5	17.09	1.14	1.58	22.91	4.51
14.09	19.8	17.65	1.14	1.50	21.29	4.27
15.09	19.3	18.16	1.12	1.44	19.88	4.05
16.09	18.7	18.71	1.12	1.37	18.64	3.86
17.09	18.2	19.22	1.11	1.32	17.55	3.68
18.09	17.8	19.72	1.10	1.27	16.58	3.52
19.09	17.4	20.24	1.10	1.22	15.71	3.38
20.09	17.0	20.74	1.09	1.18	14.93	3.25
21.09	16.6	21.21	1.09	1.14	14.23	3.14
22.09	16.3	21.69	1.08	1.10	13.58	3.02
23.09	16.0	22.15	1.08	1.07	12.99	2.92
24.09	15.7	22.63	1.08	1.03	12.45	2.83
25.09	15.5	23.09	1.07	1.01	11.96	2.74
26.09	15.2	23.60	1.07	0.97	11.50	2.66
27.09	15.0	24.01	1.06	0.95	11.08	2.58
28.09	14.8	24.47	1.06	0.93	10.68	2.51
29.09	14.6	24.90	1.05	0.90	10.31	2.44
30.09	14.3	25.34	1.06	0.88	9.97	2.38
31.08	14.1	25.80	1.06	0.86	9.65	2.32
32.08	13.9	26.27	1.06	0.84	9.35	2.26

WNPS0102.01E GNDNPS 13" PROBE GND, Permittivity 9-Jun-92 10:59:45
WNPS0102.01S GNDNPS 13" PROBE GND, Conductivity 9-Jun-92 10:59:45
Cutoff Frequency = 43.58 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	52.5	8.35	1.36	5.35	142.93	17.01
3.10	45.7	10.61	1.35	3.92	96.82	12.38
4.10	37.9	11.96	1.38	3.18	73.21	10.22
5.10	33.8	13.13	1.37	2.73	58.85	8.72
6.10	30.7	14.16	1.36	2.41	49.20	7.66
7.10	28.3	15.10	1.35	2.17	42.27	6.86
8.10	26.4	15.94	1.34	1.98	37.06	6.24
9.10	24.8	16.70	1.33	1.83	32.98	5.74
10.10	23.5	17.46	1.32	1.70	29.72	5.32
11.09	22.4	18.20	1.32	1.59	27.04	4.96
12.09	21.5	18.90	1.31	1.50	24.81	4.65
13.09	20.7	19.59	1.30	1.42	22.91	4.38
14.09	20.0	20.27	1.29	1.35	21.29	4.15
15.09	19.4	20.93	1.28	1.28	19.88	3.94
16.09	18.8	21.63	1.29	1.22	18.64	3.75
17.09	18.3	22.29	1.28	1.17	17.55	3.58
18.09	17.8	22.98	1.28	1.12	16.58	3.43
19.09	17.4	23.66	1.28	1.07	15.71	3.29
20.09	17.0	24.35	1.28	1.03	14.93	3.16
21.09	16.6	25.08	1.29	0.99	14.23	3.04
22.09	16.3	25.77	1.29	0.95	13.58	2.93
23.09	16.0	26.50	1.29	0.92	12.99	2.83
24.09	15.7	27.25	1.30	0.89	12.45	2.74
25.09	15.4	27.96	1.30	0.86	11.96	2.65
26.09	15.2	28.70	1.30	0.83	11.50	2.57
27.09	15.0	29.49	1.30	0.80	11.08	2.49
28.09	14.7	30.30	1.32	0.77	10.68	2.42
29.09	14.5	31.17	1.33	0.75	10.31	2.35
30.09	14.3	32.08	1.34	0.72	9.97	2.28
31.08	14.1	32.90	1.35	0.70	9.65	2.22
32.08	13.9	33.94	1.37	0.68	9.35	2.16

WNPS0103.01E GNDNPS 19" PROBE GND, Permittivity 9-Jun-92 11:03:25
WNPS0103.01S GNDNPS 19" PROBE GND, Conductivity 9-Jun-92 11:03:25
Cutoff Frequency = 43.58 MHz

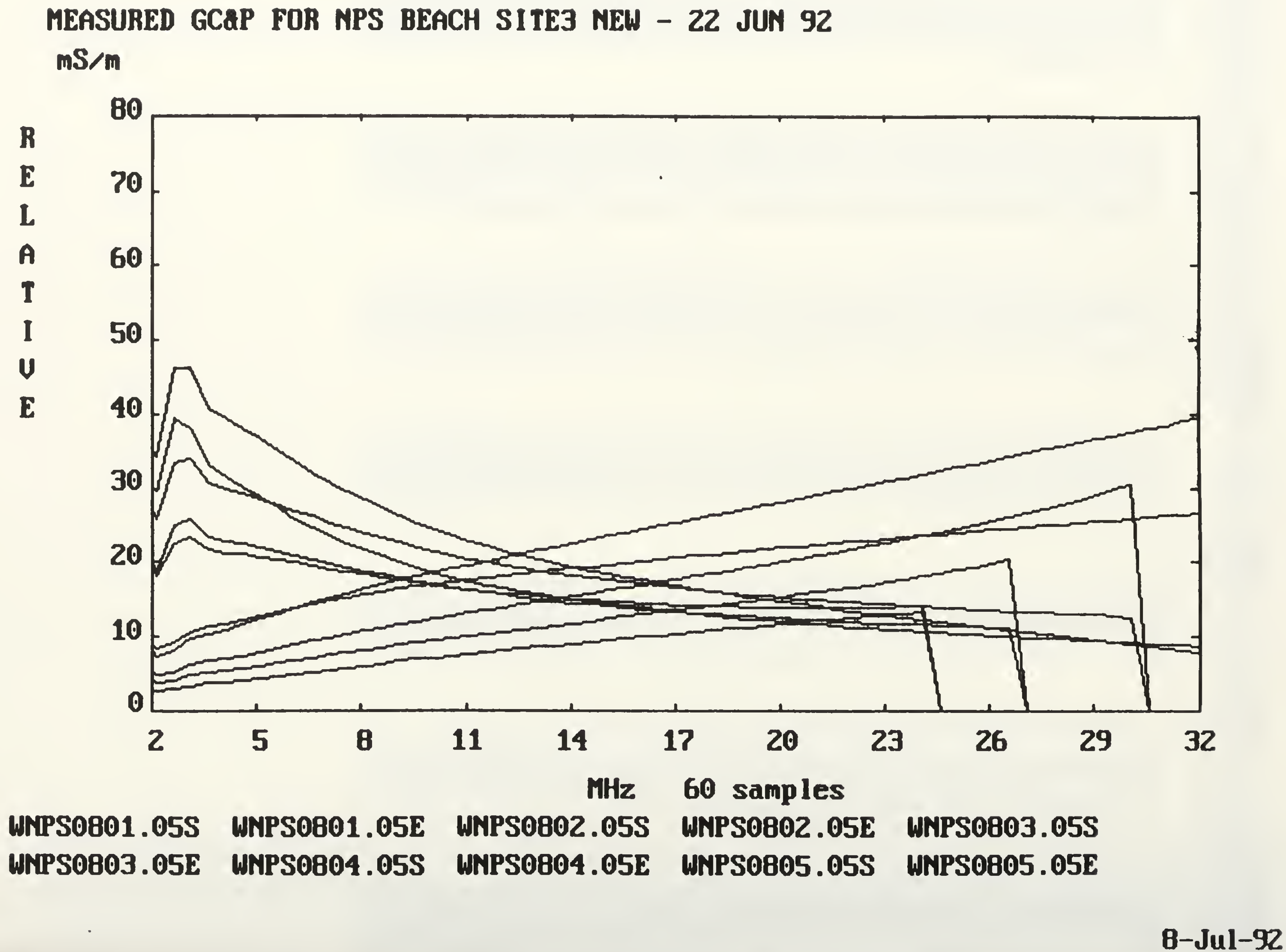
MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	35.2	3.96	0.96	8.70	142.93	22.05
3.10	32.3	5.08	0.91	6.45	96.82	15.70
4.10	28.4	6.01	0.93	5.12	73.21	12.64
5.10	26.0	6.77	0.92	4.35	58.85	10.63
6.10	24.1	7.49	0.92	3.78	49.20	9.24
7.10	22.5	8.13	0.91	3.36	42.27	8.21
8.10	21.2	8.73	0.91	3.04	37.06	7.42
9.10	20.1	9.28	0.91	2.78	32.98	6.78
10.10	19.2	9.77	0.91	2.58	29.72	6.26
11.09	18.4	10.26	0.90	2.41	27.04	5.82
12.09	17.7	10.67	0.89	2.27	24.81	5.45
13.09	17.1	11.10	0.89	2.14	22.91	5.12
14.09	16.6	11.51	0.88	2.03	21.29	4.83
15.09	16.2	11.87	0.87	1.94	19.88	4.58
16.09	15.8	12.23	0.87	1.86	18.64	4.36
17.09	15.4	12.57	0.86	1.78	17.55	4.16
18.09	15.1	12.91	0.85	1.72	16.58	3.97
19.09	14.8	13.22	0.84	1.66	15.71	3.81
20.09	14.5	13.51	0.83	1.61	14.93	3.66
21.09	14.2	13.78	0.82	1.56	14.23	3.52
22.09	14.0	14.06	0.82	1.51	13.58	3.39
23.09	13.8	14.29	0.81	1.48	12.99	3.27
24.09	13.6	14.54	0.80	1.44	12.45	3.16
25.09	13.5	14.78	0.79	1.41	11.96	3.06
26.09	13.3	14.99	0.77	1.38	11.50	2.96
27.09	13.2	15.18	0.76	1.35	11.08	2.87
28.09	13.1	15.32	0.75	1.33	10.68	2.78
29.09	13.0	15.51	0.74	1.31	10.31	2.70
30.09	12.9	15.65	0.72	1.29	9.97	2.63
31.08	12.8	15.76	0.71	1.27	9.65	2.55
32.08	12.7	15.82	0.70	1.26	9.35	2.49

WNPS0104.01E GNDNPS 25" PROBE GND, Permittivity 9-Jun-92 11:11:10
WNPS0104.01S GNDNPS 25" PROBE GND, Conductivity 9-Jun-92 11:11:10
Cutoff Frequency = 42.58 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	24.9	2.90	1.00	10.03	142.93	26.09
3.10	23.2	3.61	0.90	7.67	96.82	18.56
4.10	20.8	4.19	0.88	6.25	73.21	14.86
5.10	19.4	4.68	0.85	5.37	58.85	12.44
6.10	18.2	5.12	0.83	4.74	49.20	10.76
7.10	17.2	5.54	0.82	4.25	42.27	9.53
8.10	16.3	5.90	0.80	3.89	37.06	8.58
9.10	15.6	6.24	0.79	3.59	32.98	7.83
10.10	15.0	6.54	0.78	3.35	29.72	7.21
11.09	14.5	6.81	0.76	3.15	27.04	6.69
12.09	14.0	7.04	0.75	2.99	24.81	6.25
13.09	13.6	7.27	0.73	2.85	22.91	5.87
14.09	13.2	7.48	0.72	2.73	21.29	5.54
15.09	12.9	7.64	0.70	2.64	19.88	5.25
16.09	12.6	7.81	0.69	2.54	18.64	4.99
17.09	12.3	7.95	0.68	2.47	17.55	4.76
18.09	12.1	8.06	0.66	2.40	16.58	4.54
19.09	11.9	8.16	0.65	2.35	15.71	4.35
20.09	11.7	8.24	0.63	2.30	14.93	4.18
21.09	11.5	8.28	0.61	2.27	14.23	4.02
22.09	11.3	8.30	0.60	2.24	13.58	3.88
23.09	11.2	8.31	0.58	2.22	12.99	3.74
24.09	11.0	8.29	0.56	2.20	12.45	3.62
25.09	10.9	8.24	0.54	2.20	11.96	3.51
26.09	10.7	8.16	0.52	2.20	11.50	3.40
27.09	10.6	8.08	0.51	2.20	11.08	3.30
28.09	10.5	7.95	0.49	2.22	10.68	3.22
29.09	10.3	7.80	0.47	2.25	10.31	3.13
30.09	10.2	7.63	0.45	2.28	9.97	3.05
31.08	10.1	7.46	0.43	2.31	9.65	2.98
32.08	9.9	7.23	0.41	2.36	9.35	2.91

WNPS0105.01E GNDNPS 31" PROBE GND, Permittivity 9-Jun-92 11:15:48
WNPS0105.01S GNDNPS 31" PROBE GND, Conductivity 9-Jun-92 11:15:48
Cutoff Frequency = 40.08 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	20.5	1.83	0.77	13.96	142.93	29.72
3.10	19.0	2.32	0.71	10.52	96.82	21.07
4.10	17.3	2.76	0.70	8.44	73.21	16.69
5.10	16.2	3.13	0.68	7.18	58.85	13.90
6.10	15.3	3.46	0.67	6.30	49.20	11.99
7.10	14.5	3.76	0.66	5.64	42.27	10.58
8.10	13.9	4.03	0.65	5.14	37.06	9.51
9.10	13.3	4.26	0.63	4.75	32.98	8.66
10.10	12.8	4.44	0.62	4.46	29.72	7.96
11.09	12.4	4.62	0.61	4.21	27.04	7.39
12.09	12.0	4.77	0.59	4.01	24.81	6.90
13.09	11.6	4.88	0.58	3.85	22.91	6.48
14.09	11.3	4.98	0.56	3.71	21.29	6.11
15.09	11.0	5.04	0.55	3.62	19.88	5.79
16.09	10.7	5.11	0.53	3.52	18.64	5.51
17.09	10.5	5.13	0.51	3.46	17.55	5.26
18.09	10.3	5.14	0.50	3.41	16.58	5.03
19.09	10.1	5.12	0.48	3.38	15.71	4.82
20.09	9.9	5.06	0.46	3.38	14.93	4.64
21.09	9.7	4.99	0.44	3.39	14.23	4.47
22.09	9.5	4.89	0.42	3.42	13.58	4.32
23.09	9.3	4.77	0.40	3.46	12.99	4.18
24.09	9.1	4.62	0.38	3.53	12.45	4.05
25.09	8.9	4.48	0.36	3.60	11.96	3.94
26.09	8.8	4.30	0.34	3.71	11.50	3.83
27.09	8.6	4.08	0.32	3.86	11.08	3.74
28.09	8.4	3.90	0.30	3.99	10.68	3.65
29.09	8.2	3.67	0.28	4.19	10.31	3.57
30.09	8.0	3.46	0.26	4.38	9.97	3.49
31.08	7.8	3.22	0.24	4.65	9.65	3.42
32.08	7.6	3.01	0.22	4.91	9.35	3.36


MEASURED GC&P FOR NPS BEACH SITE3 NEW - 22 JUN 92
mS/m
RELATIVE
80
70
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32
MHz 60 samples
WNPS0801.05S WNPS0801.05E WNPS0802.05S WNPS0802.05E WNPS0803.05S
WNPS0803.05E WNPS0804.05S WNPS0804.05E WNPS0805.05S WNPS0805.05E
8-Jul-92

WNPS0801.05E GNDNPS 7" Probe GND, Permittivity 22-Jun-92 12:21:50
WNPS0801.05S GNDNPS 7" Probe GND, Conductivity 22-Jun-92 12:21:50
Cutoff Frequency = 174.01 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	29.5	8.42	2.44	4.62	142.93	19.50
3.10	37.9	10.65	1.63	3.71	96.82	13.03
4.10	31.5	11.65	1.62	3.09	73.21	10.82
5.10	28.7	12.83	1.57	2.66	58.85	9.17
6.10	25.9	13.90	1.58	2.33	49.20	8.07
7.10	23.5	14.85	1.60	2.08	42.27	7.26
8.10	21.6	15.64	1.61	1.90	37.06	6.63
9.10	20.0	16.40	1.62	1.74	32.98	6.12
10.10	18.5	17.02	1.64	1.62	29.72	5.72
11.09	17.4	17.58	1.64	1.52	27.04	5.37
12.09	16.4	18.16	1.64	1.43	24.81	5.06
13.09	15.6	18.66	1.64	1.36	22.91	4.80
14.09	14.9	19.15	1.64	1.29	21.29	4.57
15.09	14.3	19.61	1.64	1.24	19.88	4.36
16.09	13.7	20.07	1.64	1.18	18.64	4.17
17.09	13.2	20.53	1.64	1.13	17.55	4.00
18.09	12.7	21.00	1.64	1.09	16.58	3.85
19.09	12.3	21.43	1.64	1.05	15.71	3.71
20.09	11.9	21.84	1.64	1.01	14.93	3.58
21.09	11.6	22.27	1.64	0.98	14.23	3.46
22.09	11.2	22.70	1.65	0.95	13.58	3.35
23.09	10.9	23.11	1.65	0.92	12.99	3.25
24.09	10.6	23.52	1.65	0.89	12.45	3.16
25.09	10.4	23.90	1.65	0.87	11.96	3.07
26.09	10.1	24.32	1.66	0.84	11.50	2.99
27.09	9.9	24.71	1.66	0.82	11.08	2.91
28.09	9.6	25.09	1.67	0.80	10.68	2.84
29.09	9.4	25.45	1.68	0.78	10.31	2.77
30.09	9.2	25.83	1.69	0.76	9.97	2.71
31.08	8.9	26.20	1.69	0.74	9.65	2.65
32.08	8.7	26.55	1.70	0.72	9.35	2.59

WNPS0802.05E GNDNPS 13" PROBE GND, Permittivity 22-Jun-92 12:24:
WNPS0802.05S GNDNPS 13" PROBE GND, Conductivity 22-Jun-92 12:24:
Cutoff Frequency = 34.58 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	34.2	7.26	1.82	5.31	142.93	19.71
3.10	46.2	9.62	1.21	4.25	96.82	12.57
4.10	39.3	10.84	1.21	3.48	73.21	10.30
5.10	36.6	12.36	1.19	2.94	58.85	8.60
6.10	33.6	13.85	1.21	2.52	49.20	7.48
7.10	30.8	15.22	1.25	2.21	42.27	6.68
8.10	28.4	16.42	1.28	1.98	37.06	6.07
9.10	26.3	17.63	1.32	1.78	32.98	5.57
10.10	24.4	18.69	1.36	1.63	29.72	5.18
11.09	22.9	19.66	1.39	1.51	27.04	4.85
12.09	21.5	20.66	1.43	1.40	24.81	4.57
13.09	20.4	21.60	1.46	1.31	22.91	4.32
14.09	19.3	22.53	1.49	1.22	21.29	4.10
15.09	18.3	23.48	1.52	1.15	19.88	3.91
16.09	17.5	24.38	1.56	1.09	18.64	3.73
17.09	16.7	25.31	1.60	1.03	17.55	3.58
18.09	15.9	26.23	1.64	0.98	16.58	3.44
19.09	15.3	27.21	1.68	0.93	15.71	3.31
20.09	14.6	28.06	1.72	0.88	14.93	3.20
21.09	14.0	29.07	1.77	0.84	14.23	3.09
22.09	13.4	29.99	1.83	0.80	13.58	2.99
23.09	12.8	30.90	1.88	0.77	12.99	2.90
24.09	12.2	31.81	1.94	0.74	12.45	2.82
25.09	11.7	32.76	2.01	0.71	11.96	2.75
26.09	11.2	33.78	2.08	0.68	11.50	2.67
27.09	10.6	34.70	2.16	0.65	11.08	2.61
28.09	10.0	35.68	2.27	0.62	10.68	2.55
29.09	9.5	36.62	2.38	0.60	10.31	2.50
30.09	8.9	37.60	2.51	0.57	9.97	2.45
31.08	8.4	38.43	2.65	0.55	9.65	2.41
32.08	7.9	39.48	2.82	0.53	9.35	2.36

WNPS0803.05E GNDNPS 19" PROBE GND, Permittivity 22-Jun-92 12:27:22
WNPS0803.05S GNDNPS 19" PROBE GND, Conductivity 22-Jun-92 12:27:22
Cutoff Frequency = 30.58 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	25.9	4.86	1.61	6.69	142.93	23.35
3.10	33.9	6.15	1.05	5.57	96.82	15.02
4.10	29.9	6.95	1.02	4.61	73.21	12.14
5.10	28.6	7.89	0.97	3.94	58.85	10.05
6.10	27.0	8.89	0.97	3.40	49.20	8.66
7.10	25.4	9.84	0.98	2.98	42.27	7.66
8.10	24.0	10.70	0.99	2.67	37.06	6.90
9.10	22.7	11.61	1.01	2.40	32.98	6.29
10.10	21.4	12.42	1.03	2.19	29.72	5.81
11.09	20.4	13.16	1.04	2.02	27.04	5.41
12.09	19.6	13.92	1.06	1.87	24.81	5.06
13.09	18.8	14.66	1.07	1.74	22.91	4.76
14.09	18.1	15.39	1.08	1.63	21.29	4.50
15.09	17.5	16.14	1.10	1.53	19.88	4.26
16.09	17.0	16.87	1.11	1.45	18.64	4.05
17.09	16.4	17.66	1.13	1.37	17.55	3.87
18.09	16.0	18.41	1.14	1.30	16.58	3.69
19.09	15.6	19.21	1.16	1.23	15.71	3.54
20.09	15.2	20.02	1.18	1.17	14.93	3.40
21.09	14.8	20.83	1.20	1.11	14.23	3.26
22.09	14.6	21.70	1.21	1.06	13.58	3.14
23.09	14.3	22.57	1.23	1.01	12.99	3.02
24.09	14.0	23.50	1.25	0.96	12.45	2.92
25.09	13.8	24.43	1.27	0.92	11.96	2.82
26.09	13.5	25.43	1.30	0.88	11.50	2.72
27.09	13.3	26.52	1.33	0.84	11.08	2.64
28.09	13.0	27.74	1.36	0.80	10.68	2.55
29.09	12.9	29.00	1.39	0.77	10.31	2.47
30.09	12.6	30.51	1.45	0.73	9.97	2.39

WNPS0804.05E GNDNPS 25" PROBE GND, Permittivity 22-Jun-92 12:30:
WNPS0804.05S GNDNPS 25" PROBE GND, Conductivity 22-Jun-92 12:30:
Cutoff Frequency = 27.09 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	18.8	3.87	1.76	7.33	142.93	26.78
3.10	25.7	4.76	1.07	6.29	96.82	17.19
4.10	22.7	5.34	1.03	5.23	73.21	13.92
5.10	21.9	6.00	0.96	4.53	58.85	11.50
6.10	20.9	6.73	0.95	3.93	49.20	9.87
7.10	19.8	7.44	0.95	3.47	42.27	8.71
8.10	18.8	8.11	0.96	3.10	37.06	7.83
9.10	17.9	8.81	0.97	2.79	32.98	7.12
10.10	17.0	9.45	0.99	2.54	29.72	6.57
11.09	16.2	10.01	1.00	2.35	27.04	6.12
12.09	15.6	10.60	1.01	2.18	24.81	5.71
13.09	15.0	11.18	1.02	2.03	22.91	5.37
14.09	14.5	11.75	1.04	1.90	21.29	5.07
15.09	14.0	12.32	1.05	1.79	19.88	4.80
16.09	13.6	12.88	1.06	1.69	18.64	4.56
17.09	13.2	13.48	1.07	1.59	17.55	4.35
18.09	12.9	14.06	1.08	1.51	16.58	4.15
19.09	12.6	14.64	1.09	1.43	15.71	3.97
20.09	12.3	15.27	1.11	1.36	14.93	3.81
21.09	12.1	15.91	1.12	1.30	14.23	3.66
22.09	11.9	16.60	1.14	1.24	13.58	3.51
23.09	11.7	17.31	1.15	1.18	12.99	3.38
24.09	11.5	18.09	1.17	1.12	12.45	3.26
25.09	11.3	18.88	1.20	1.07	11.96	3.14
26.09	11.2	19.78	1.22	1.02	11.50	3.03

WNPS0805.05E GNDNPS 31" PROBE GND, Permittivity 22-Jun-92 12:32:21
WNPS0805.05S GNDNPS 31" PROBE GND, Conductivity 22-Jun-92 12:32:21
Cutoff Frequency = 24.59 MHz

MHz	Er	mS/m	D.F.	S.D.	W air	W gnd
2.10	18.1	2.77	1.31	9.39	142.93	29.20
3.10	23.5	3.28	0.81	8.39	96.82	18.69
4.10	21.3	3.78	0.78	6.90	73.21	14.91
5.10	20.7	4.31	0.73	5.94	58.85	12.21
6.10	19.9	4.89	0.72	5.13	49.20	10.43
7.10	19.1	5.49	0.73	4.47	42.27	9.15
8.10	18.3	6.02	0.73	4.00	37.06	8.18
9.10	17.6	6.60	0.74	3.58	32.98	7.41
10.10	16.9	7.11	0.75	3.26	29.72	6.82
11.09	16.3	7.58	0.75	3.00	27.04	6.31
12.09	15.8	8.07	0.76	2.78	24.81	5.87
13.09	15.4	8.52	0.76	2.60	22.91	5.50
14.09	15.0	8.98	0.76	2.43	21.29	5.17
15.09	14.7	9.43	0.76	2.29	19.88	4.88
16.09	14.4	9.87	0.76	2.17	18.64	4.62
17.09	14.2	10.33	0.77	2.06	17.55	4.38
18.09	14.0	10.75	0.76	1.96	16.58	4.17
19.09	13.9	11.20	0.76	1.88	15.71	3.97
20.09	13.8	11.65	0.75	1.80	14.93	3.78
21.09	13.7	12.05	0.75	1.73	14.23	3.62
22.09	13.8	12.51	0.74	1.67	13.58	3.45
23.09	13.9	12.87	0.72	1.62	12.99	3.30
24.09	14.0	13.20	0.70	1.59	12.45	3.15

APPENDIX B. NEC DATA SETS

```
CM          --------- MULTIBAND DIPOLE (3-DIPOLES) ---------
CM
CM
CM     GEOMETRY:                 1ST        2ND        3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft       40ft       39ft
CM                   LENGTH:  81ft     42.8ft       28ft
CM                 DIAMETER:  1/16"      1/16"      1/16"
CM    FREQUENCY: 5.6 MHz
CM   NPS GROUND: EPSILON = 25.54 , SIGMA = 9.25 mS/m
CE
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,25.54,0.00925,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM          --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM    GEOMETRY:                    1ST         2ND         3RD (DIPOLE)
CM          HEIGHT CENTER:  41ft        40ft        39ft
CM                 LENGTH:  81ft      42.8ft        28ft
CM               DIAMETER:  1/16"      1/16"       1/16"
CM   FREQUENCY: 11. MHz
CM  NPS GROUND: EPSILON = 18.32 , SIGMA = 13.33 mS/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.0,0.,
GN2,0,0,0,18.32,0.01333,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM             --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                   1ST         2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM    FREQUENCY: 16.8 MHz
CM   NPS GROUND: EPSILON = 14.65 , SIGMA = 16.82 mS/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,14.65,0.01682,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,85.,0.,0.,1.,0.,0.,
RP0,1,361,1000,80.,0.,0.,1.,0.,0.,
RP0,1,361,1000,74.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM            --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                   1ST        2ND        3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft       40ft       39ft
CM                   LENGTH:  81ft     42.8ft       28ft
CM                 DIAMETER:  1/16"      1/16"      1/16"
CM    FREQUENCY:  5.6 MHz
CM   WET TUNDRA:  EPSILON = 55,  SIGMA = 0.017 S/m
CM
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,55.,0.017,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM          --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM    GEOMETRY:                  1ST        2ND        3RD (DIPOLE)
CM             HEIGHT CENTER:    41ft       40ft       39ft
CM                    LENGTH:    81ft     42.8ft       28ft
CM                  DIAMETER:    1/16"      1/16"      1/16"
CM    FREQUENCY:  11 MHz
CM   WET TUNDRA:  EPSILON = 40,  SIGMA = 0.018 S/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.,0.,
GN2,0,0,0,40.,0.018,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM          --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                   1ST         2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM    FREQUENCY:  16.8 MHz
CM   WET TUNDRA:  EPSILON = 33,  SIGMA= 0.021 S/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,33.,0.021,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM            --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                  1ST        2ND         3RD (DIPOLE)
CM             HEIGHT CENTER:  41ft        40ft        39ft
CM                    LENGTH:  81ft      42.8ft        28ft
CM                  DIAMETER:  1/16"       1/16"       1/16"
CM    FREQUENCY:  5.6 MHz
CM   DRY TUNDRA:  EPSILON = 20,  SIGMA = 0.0055 S/m
CE
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,20.,0.0055,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM            --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM    GEOMETRY:                  1ST         2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM   FREQUENCY:  11 MHz
CM  DRY TUNDRA:  EPSILON = 16,  SIGMA = 0.0062 S/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.0,0.,
GN2,0,0,0,16.,0.0062,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

```
CM           --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                  1ST        2ND        3RD (DIPOLE)
CM              HEIGHT CENTER:  41ft       40ft       39ft
CM                     LENGTH:  81ft     42.8ft       28ft
CM                   DIAMETER:  1/16"      1/16"      1/16"
CM   FREQUENCY:  16.8 MHz
CM  DRY TUNDRA:  EPSILON = 11,  SIGMA = 0.0068 S/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,11.,0.0068,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM          --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                    1ST         2ND         3RD (DIPOLE)
CM              HEIGHT CENTER:      41ft        40ft        39ft
CM                     LENGTH:      81ft      42.8ft        28ft
CM                   DIAMETER:      1/16"       1/16"       1/16"
CM      FREQUENCY:  5.6 MHz
CM  FROZEN TUNDRA:  EPSILON = 12,  SIGMA = 0.0017 S/m
CE
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,12.,0.0017,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM           --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM    GEOMETRY:                 1ST        2ND        3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft       40ft       39ft
CM                   LENGTH:  81ft     42.8ft       28ft
CM                 DIAMETER:  1/16"      1/16"      1/16"
CM    FREQUENCY:  11 MHz
CM FROZEN TUNDRA:  EPSILON= 8.7,  SIGMA = 0.0026 S/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.,0.,
GN2,0,0,0,8.7,0.0026,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM            --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                  1ST         2ND         3RD (DIPOLE)
CM           HEIGHT CENTER:  41ft        40ft        39ft
CM                  LENGTH:  81ft      42.8ft        28ft
CM                DIAMETER:  1/16"       1/16"       1/16"
CM     FREQUENCY:  16.8 MHz
CM FROZEN TUNDRA:  EPSILON = 7,  SIGMA = 0.003 S/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,7.,0.003,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM        --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM      GEOMETRY:                 1ST        2ND        3RD (DIPOLE)
CM             HEIGHT CENTER:     41ft       40ft       39ft
CM                    LENGTH:     81ft     42.8ft       28ft
CM                  DIAMETER:     1/16"      1/16"      1/16"
CM       FREQUENCY:   5.6 MHz
CM AVERAGE GROUND:   EPSILON = 10  , SIGMA = 0.003 S/m
CE
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,10.,0.003,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

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CM        --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM      GEOMETRY:                  1ST         2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM       FREQUENCY:   11. MHz
CM AVERAGE GROUND:   EPSILON = 10   , SIGMA = 0.003 S/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.,0.,
GN2,0,0,0,10.,0.003,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM      --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                1ST        2ND        3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft       40ft       39ft
CM                   LENGTH:  81ft     42.8ft       28ft
CM                 DIAMETER:  1/16"      1/16"      1/16"
CM      FREQUENCY:  16.8 MHz
CM AVERAGE GROUND:   EPSILON = 10  , SIGMA = 0.003 S/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,10.,0.003,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM        --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                   1ST         2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM      FREQUENCY:   5.6 MHz
CM     FAIR GROUND:   EPSILON = 12  , SIGMA = 0.005 S/m
CE
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,12.,0.005,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
```

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CM       --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM    GEOMETRY:                   1ST         2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM     FREQUENCY:   11. MHz
CM    FAIR GROUND:   EPSILON = 12  , SIGMA = 0.005 S/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.,0.,
GN2,0,0,0,12.,0.005,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM       --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                  1ST         2ND          3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft         39ft
CM                   LENGTH:  81ft      42.8ft         28ft
CM                 DIAMETER:  1/16"       1/16"        1/16"
CM      FREQUENCY:  16.8 MHz
CM     FAIR GROUND:   EPSILON = 12  , SIGMA = 0.005 S/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,12.,0.005,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM          --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM    GEOMETRY:                    1ST        2ND        3RD (DIPOLE)
CM              HEIGHT CENTER:  41ft       40ft       39ft
CM                     LENGTH:  81ft     42.8ft       28ft
CM                   DIAMETER:  1/16"      1/16"      1/16"
CM    FREQUENCY: 5.6 MHz
CM  POOR GROUND: EPSILON = 5  , SIGMA = 0.001 S/m
CE
GW3,12,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.059,0.0008,0.0008,
GW9,6,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.129,0.0008,0.0008,
GW15,4,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.25,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,5.6,0.,
GN2,0,0,0,5.,0.001,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM             --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM
CM     GEOMETRY:                   1ST        2ND         3RD (DIPOLE)
CM            HEIGHT CENTER:  41ft        40ft        39ft
CM                   LENGTH:  81ft      42.8ft        28ft
CM                 DIAMETER:  1/16"       1/16"       1/16"
CM    FREQUENCY: 11. MHz
CM  POOR GROUND: EPSILON = 5  , SIGMA = 0.001 S/m
CE
GW3,23,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.018,.0008,.0008,
GW9,12,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.036,.0008,.0008,
GW15,8,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.086,.0008,.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,11.,0.,
GN2,0,0,0,5.,0.001,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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CM           --------- MULTIBAND DIPOLE  (3-DIPOLES) ---------
CM
CM
CM    GEOMETRY:                      1ST        2ND        3RD (DIPOLE)
CM              HEIGHT CENTER:       41ft       40ft       39ft
CM                     LENGTH:       81ft     42.8ft       28ft
CM                   DIAMETER:       1/16"      1/16"      1/16"
CM    FREQUENCY: 16.8 MHz
CM  POOR GROUND: EPSILON = 5  , SIGMA = 0.001 S/m
CE
GW3,34,0.,.175,12.5,0.,12.28,14.90,0.,
GC0,0,1.0045,0.0008,0.0008,
GW9,18,0.,.175,12.19,0.,6.70,12.19,0.,
GC0,0,1.0085,0.0008,0.0008,
GW15,11,0.,.175,11.88,0.,4.36,11.05,0,
GC0,0,1.049,0.0008,0.0008,
GW2,2,0.,.175,11.88,0.,.175,12.5,0.0008,
GW1,1,0.,0.,11.88,0.,.175,11.88,0.0008,
GX0,010,
GE1,0,0,
EX0,1,1,01,1.0,0.0,0.,
EX0,1,2,01,-1.0,0.,0.,
FR0,1,0,0,16.8,0.,
GN2,0,0,0,5.,0.001,
RP0,91,7,1501,0.,0.,1.,15.,0.,0.,
RP0,181,0,1000,-90.,0.,1.,0.,0.,0.,
RP0,1,361,1000,65.,0.,0.,1.,0.,0.,
RP0,1,361,1000,60.,0.,0.,1.,0.,0.,
RP0,1,361,1000,55.,0.,0.,1.,0.,0.,
RP0,1,361,1000,50.,0.,0.,1.,0.,0.,
RP0,1,361,1000,45.,0.,0.,1.,0.,0.,
RP0,1,361,1000,40.,0.,0.,1.,0.,0.,
RP0,1,361,1000,35.,0.,0.,1.,0.,0.,
RP0,1,361,1000,30.,0.,0.,1.,0.,0.,
RP0,181,1,1000,-90.,90.,1.,0.,0.,0.,
EN
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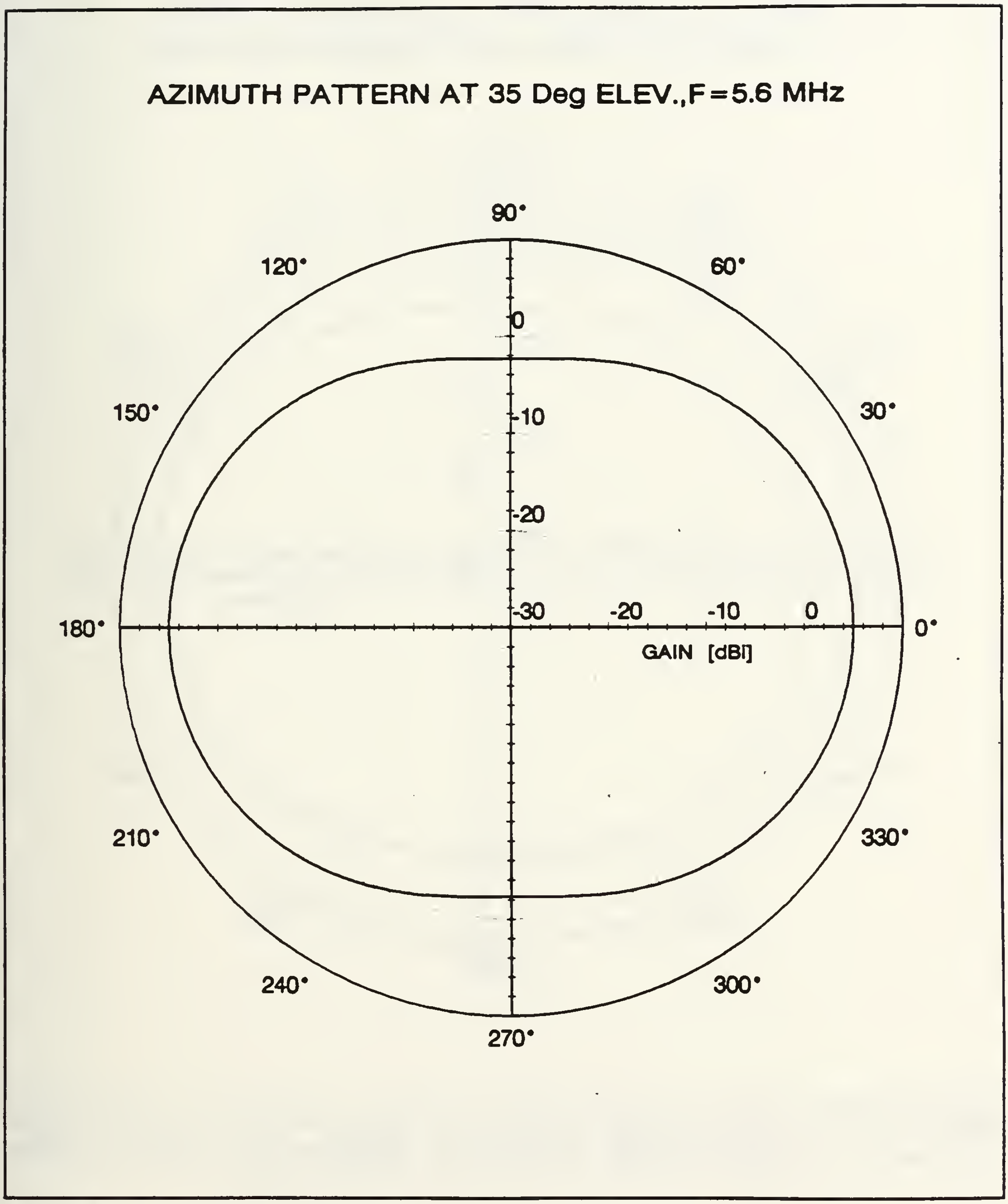

Figure 14: Azimuth Rad. Pattern, Elev. 35°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

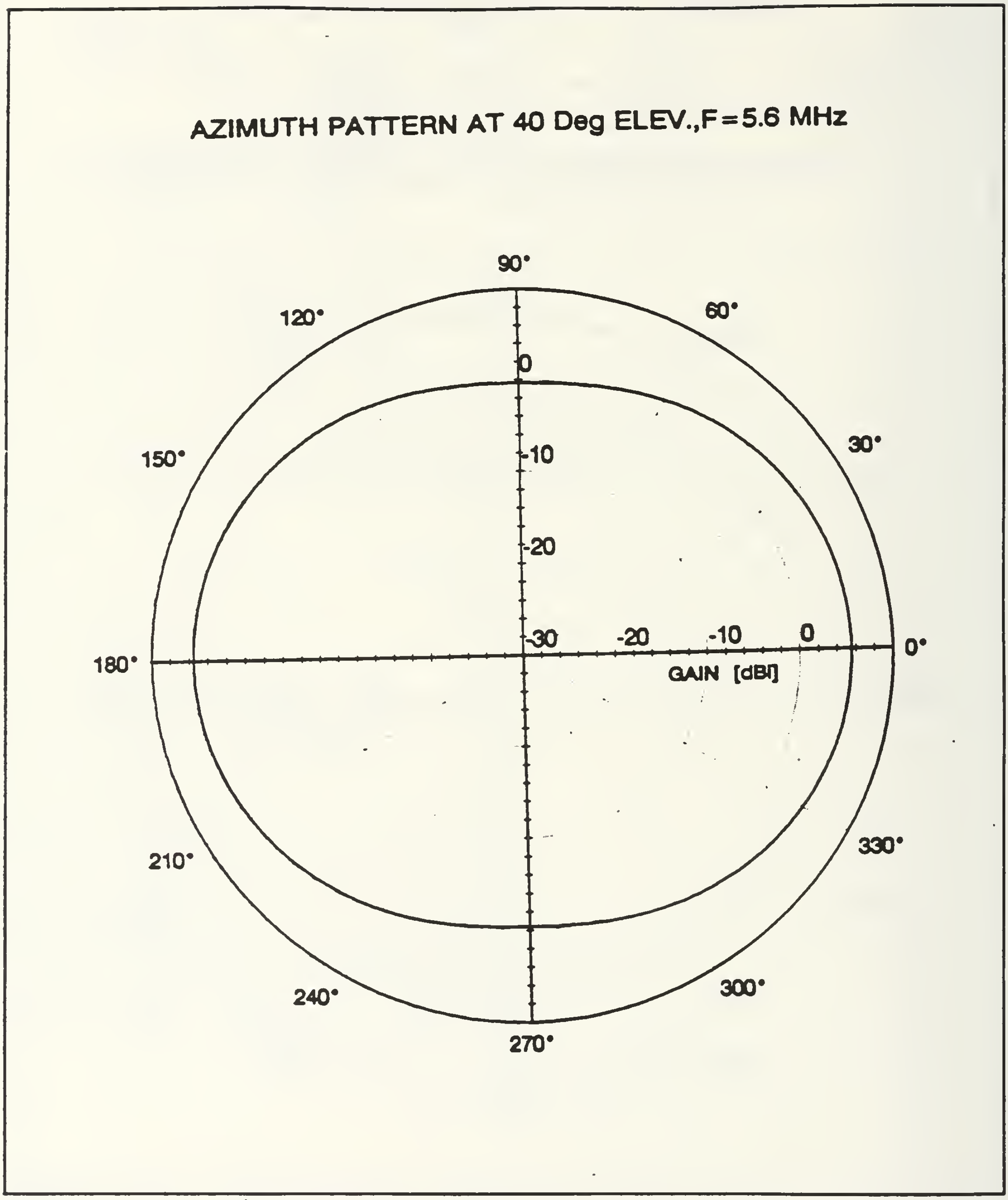

Figure 15: Azimuth Rad. Pattern, Elev. 40°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

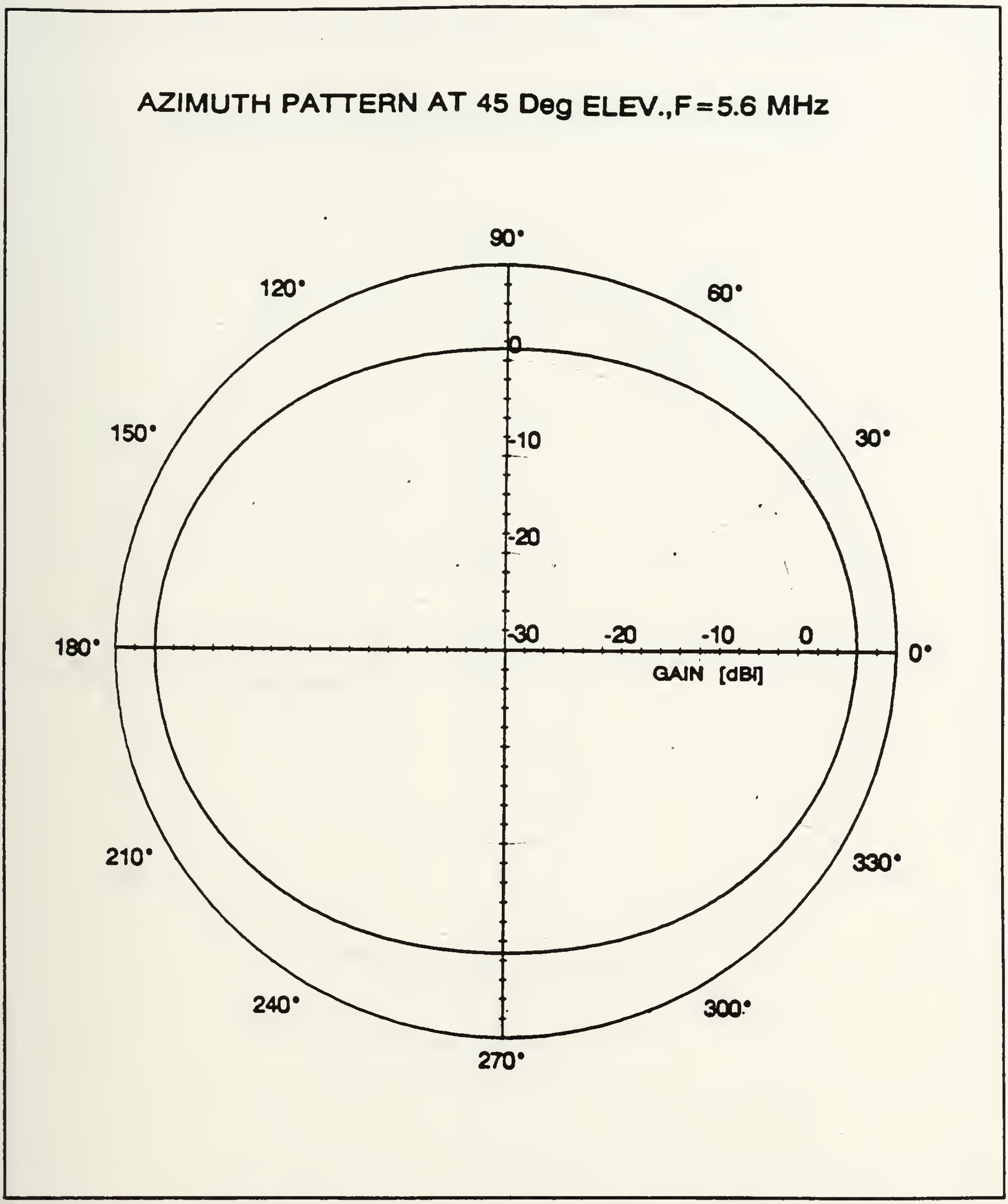

Figure 16: Azimuth Rad. Pattern, Elev. 45°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

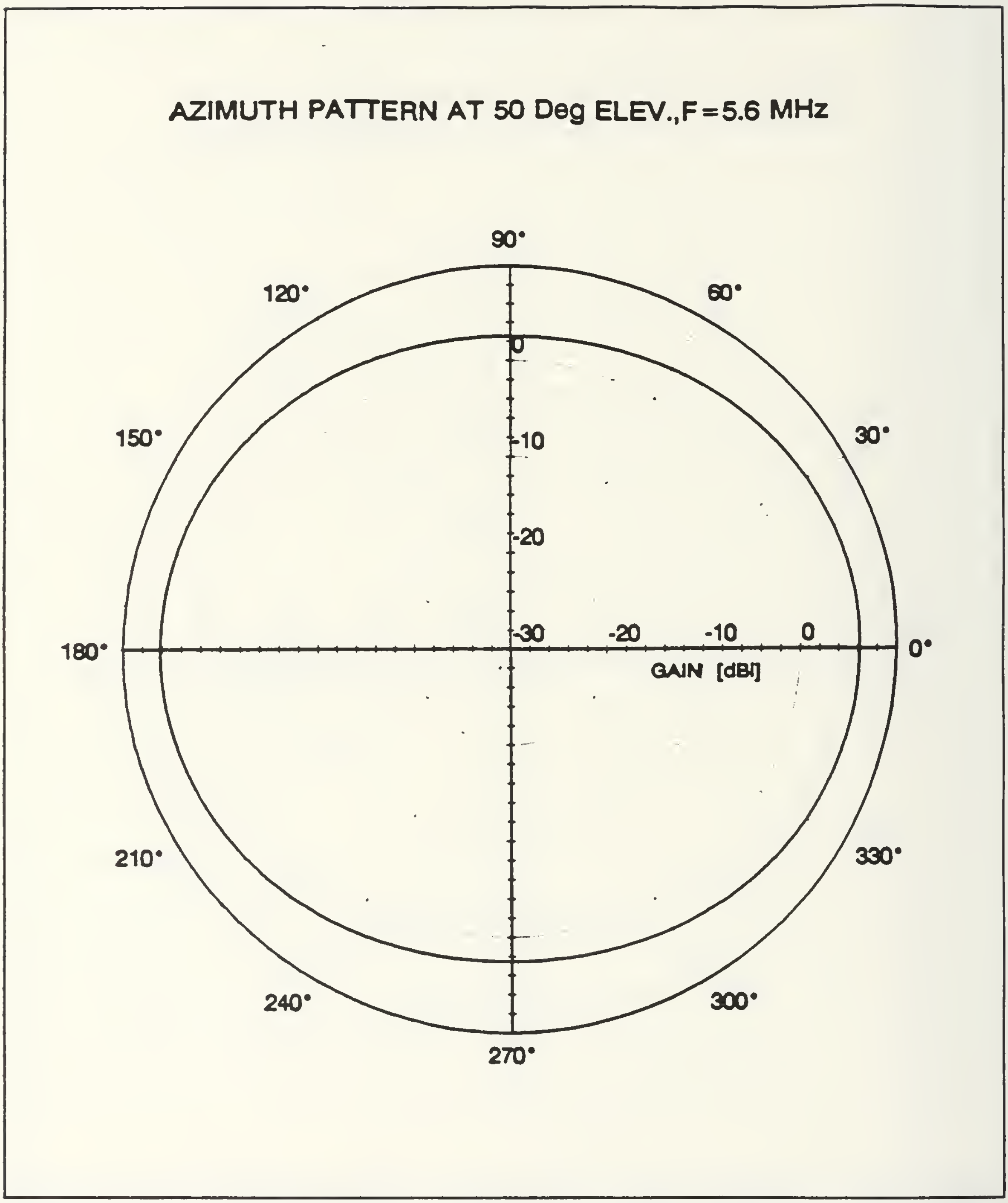

Figure 17: Azimuth Rad. Pattern, Elev. 50°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

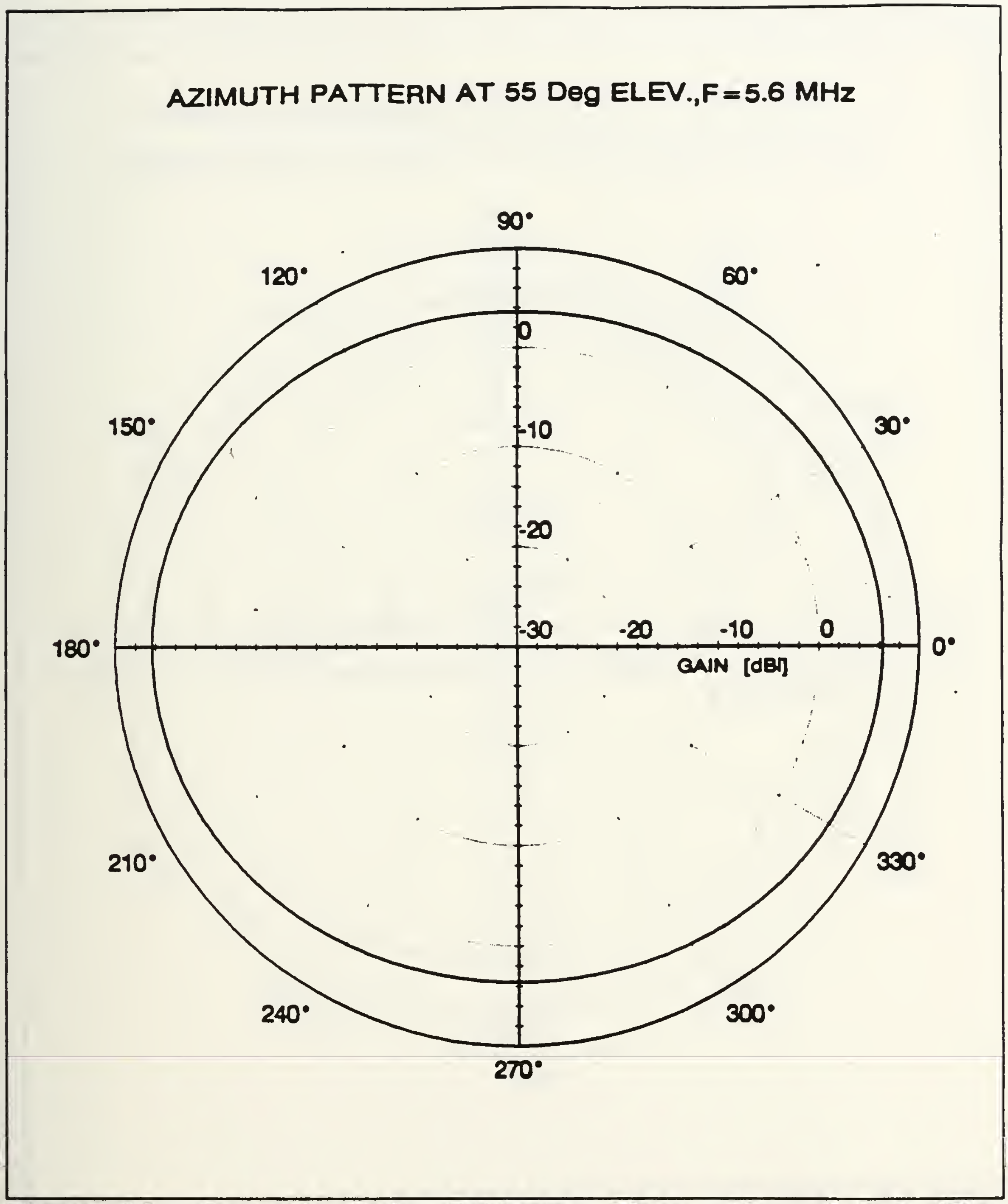

Figure 18: Azimuth Rad. Pattern, Elev. 55°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

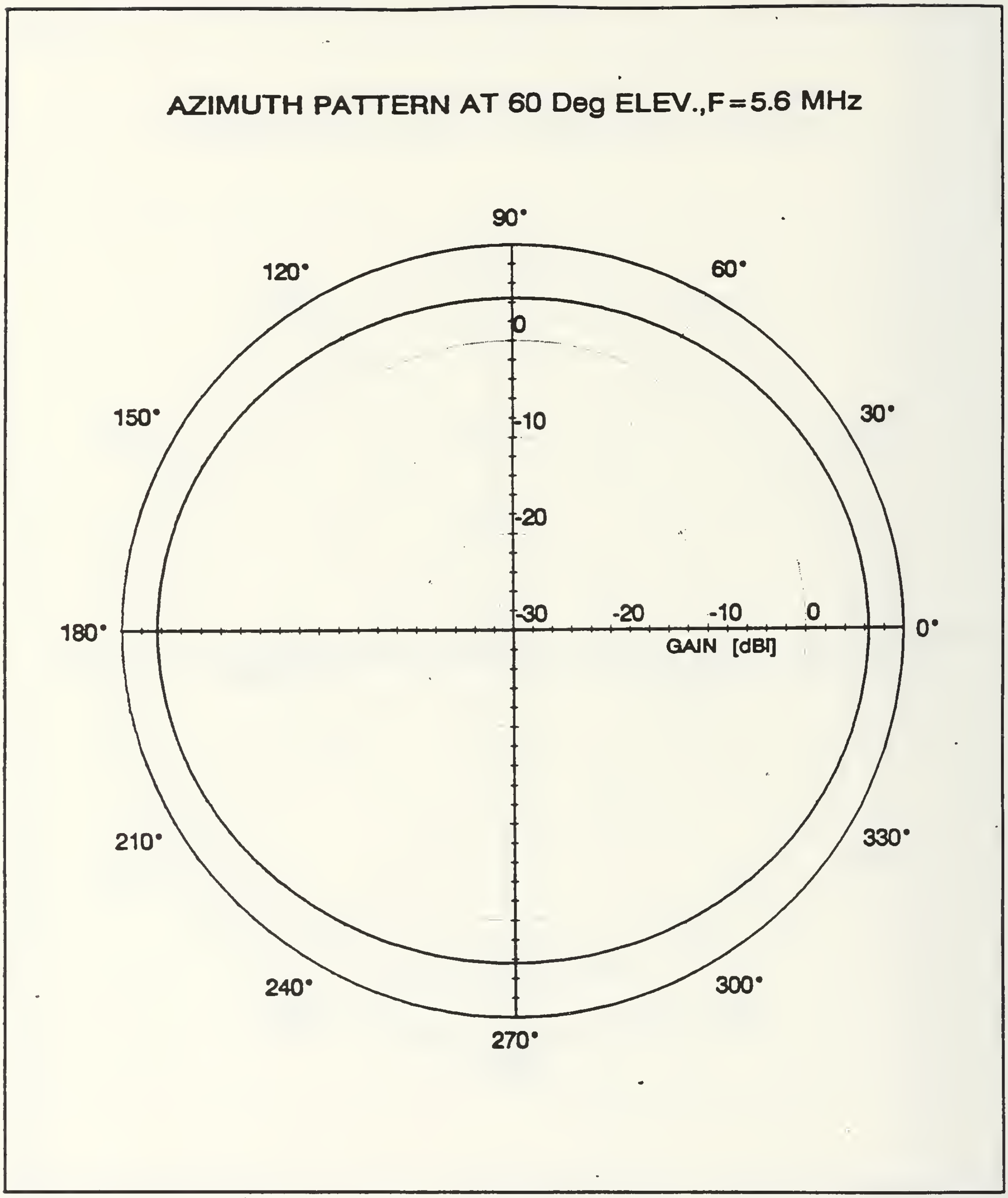

Figure 19: Azimuth Rad. Pattern, Elev. 60°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

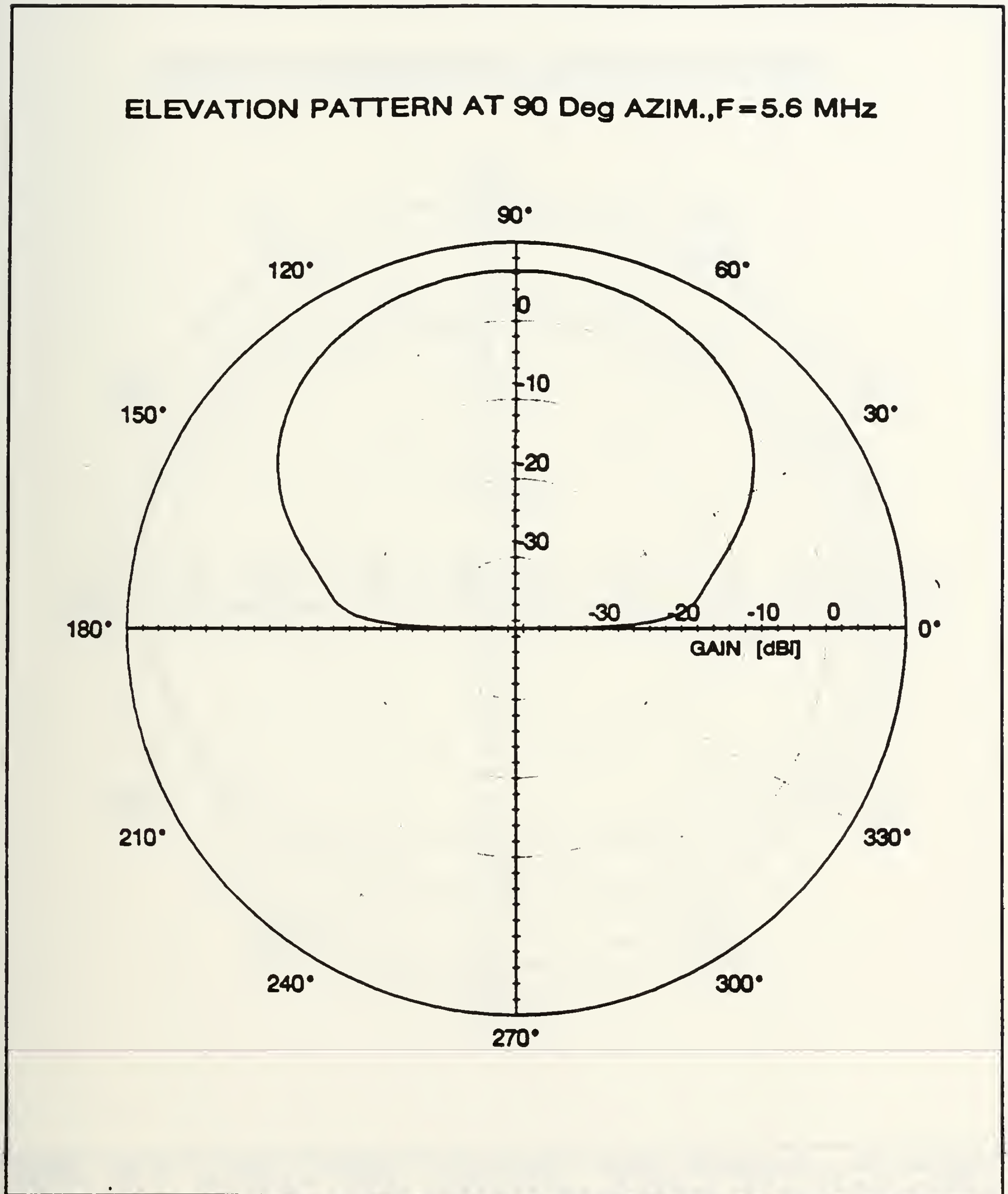

Figure 20: Elevation Rad. Pattern, Azim. 90°, f=5.6 MHz, Multiband Dipole Antenna at the NPS Beach site.

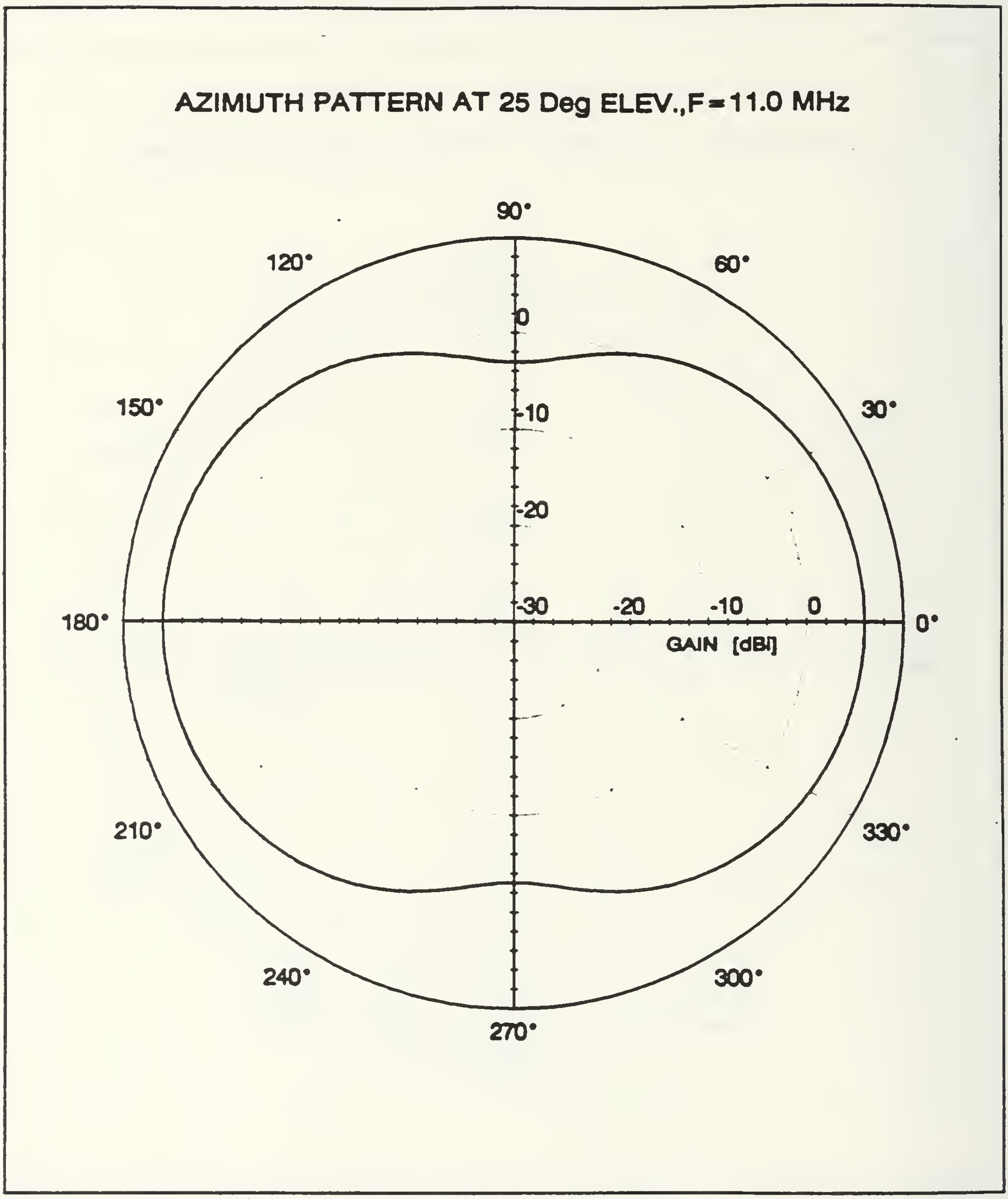

Figure 21: Azimuth Rad. Pattern, Elev. 25°, f=11 MHz, Multiband Dipole Antenna at the NPS Beach site.

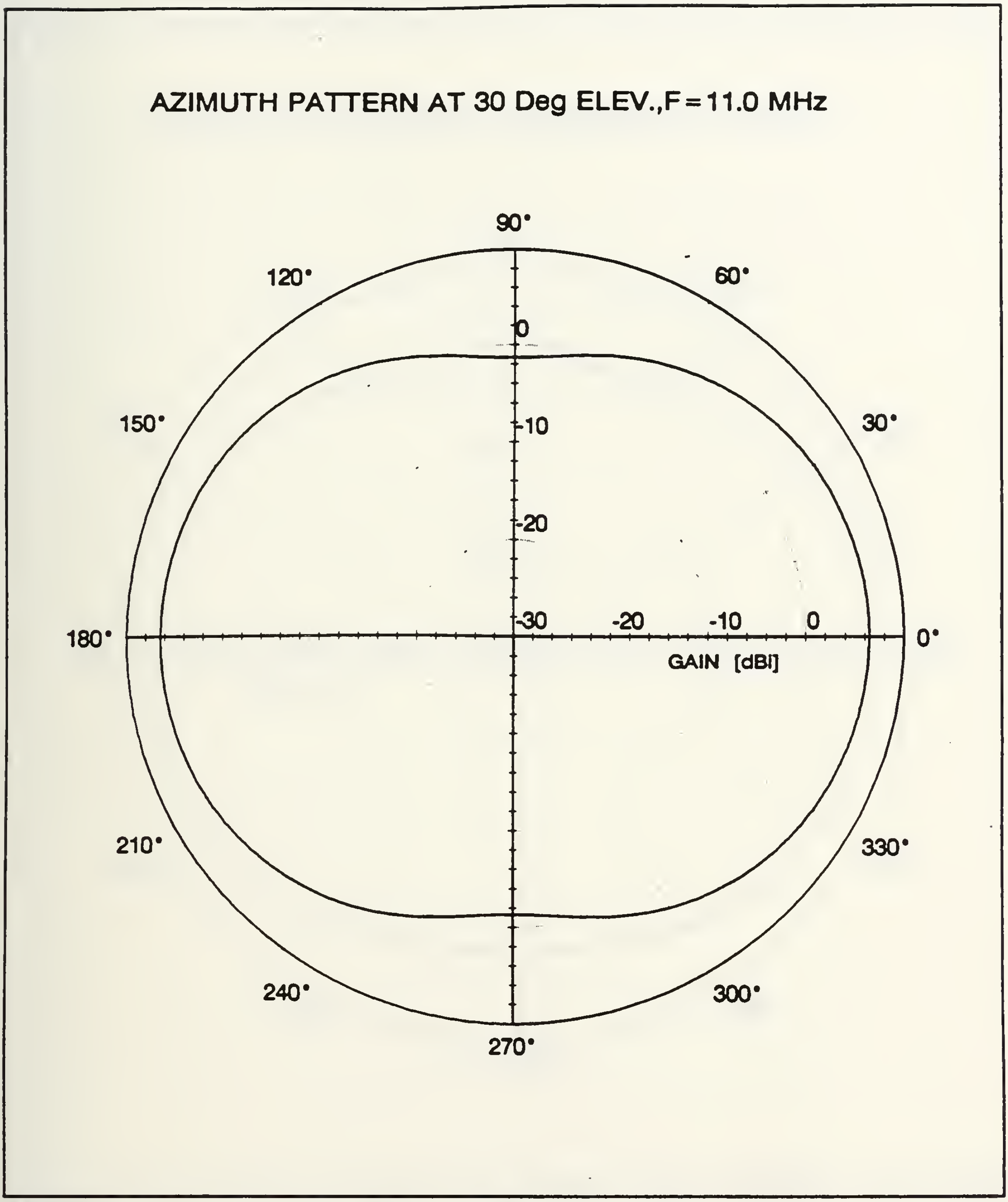

Figure 22: Azimuth Rad. Pattern, Elev. 30°, f=11 MHz, Multiband Dipole Antenna at NPS Beach site.

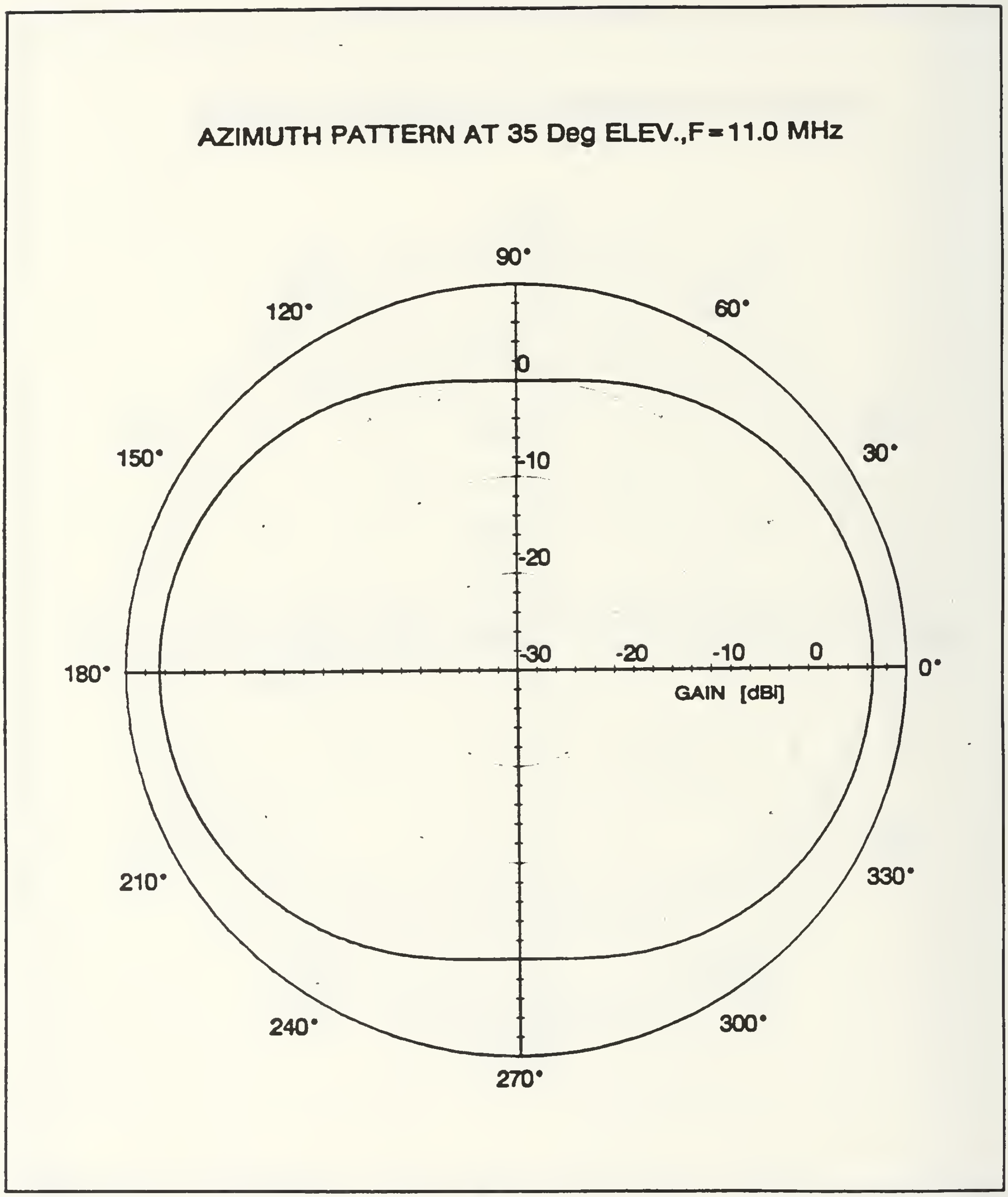

Figure 23: Azimuth Rad. Pattern, Elev. 35°, f=11 MHz, Multiband Dipole Antenna at the NPS Beach site.

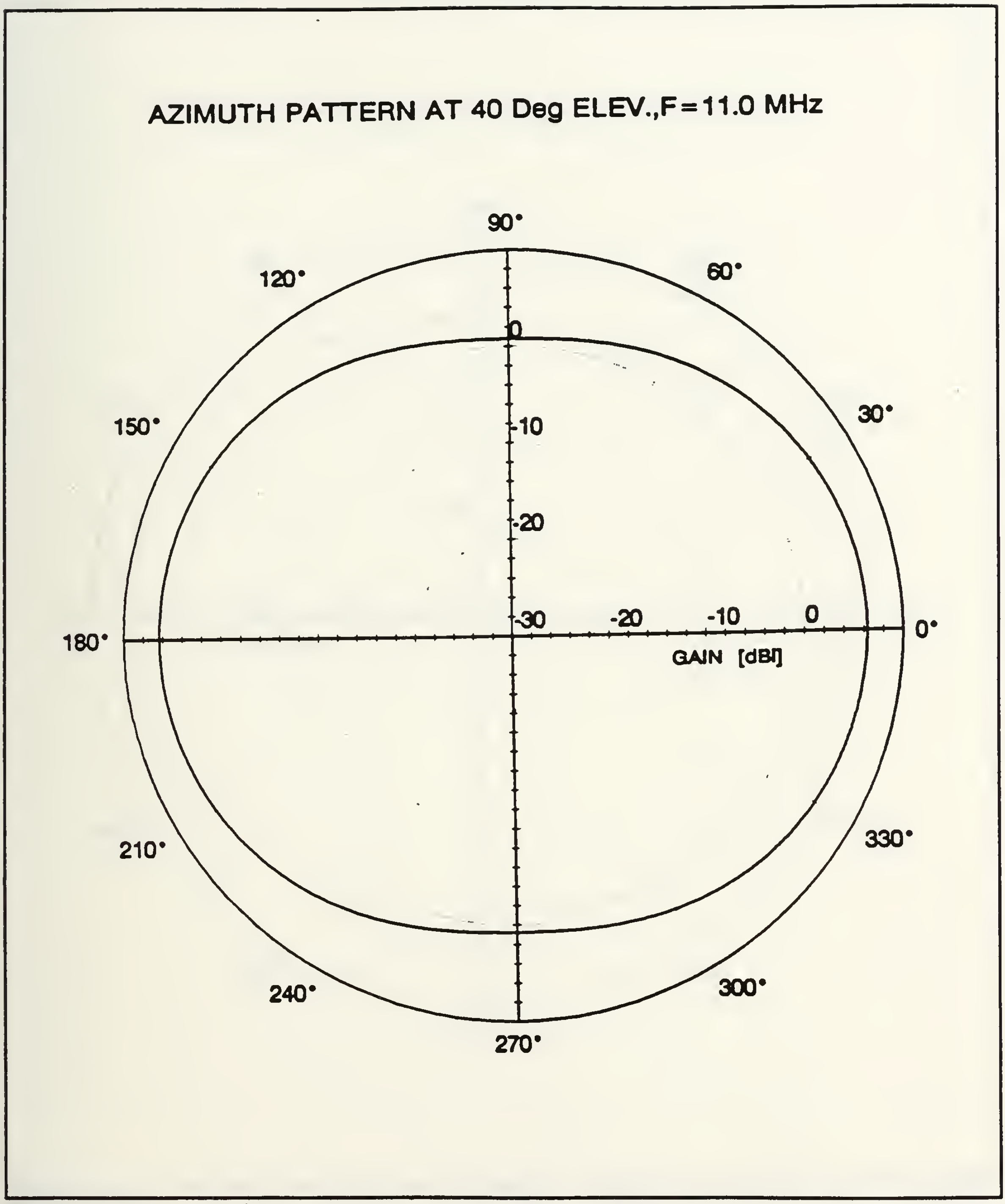

Figure 24: Azimuth Rad. Pattern, Elev. 40°, f=11 MHz, Multiband Dipole Antenna at the NPS Beach site.

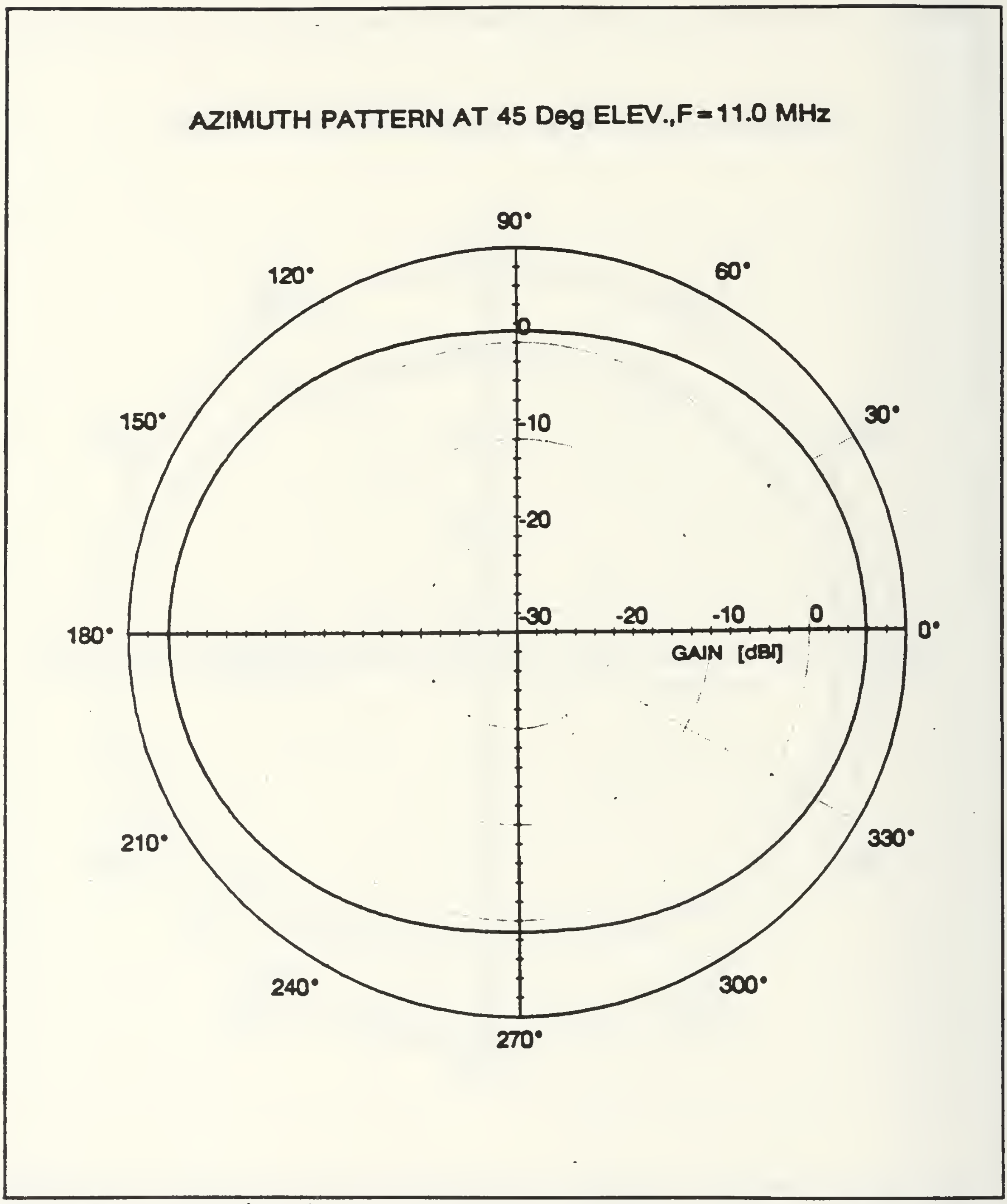

Figure 25: Azimuth Rad. Pattern, Elev. 45°, f=11 MHz, Multiband Dipole Antenna at NPS Beach site.

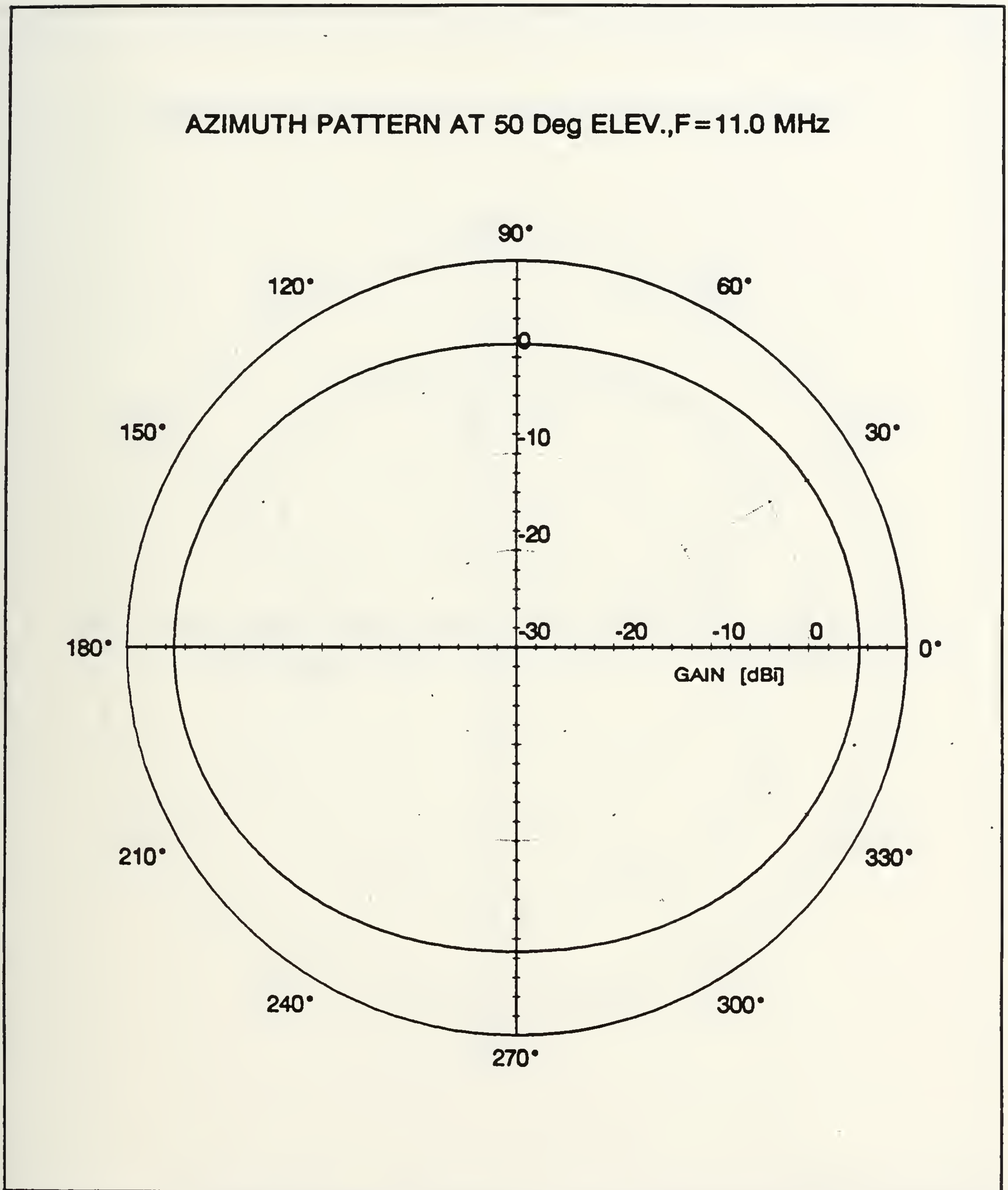

Figure 26: Azimuth Rad. Pattern, Elev. 50°, f=11 MHz, Multiband Dipole Antenna at the NPS Beach site.

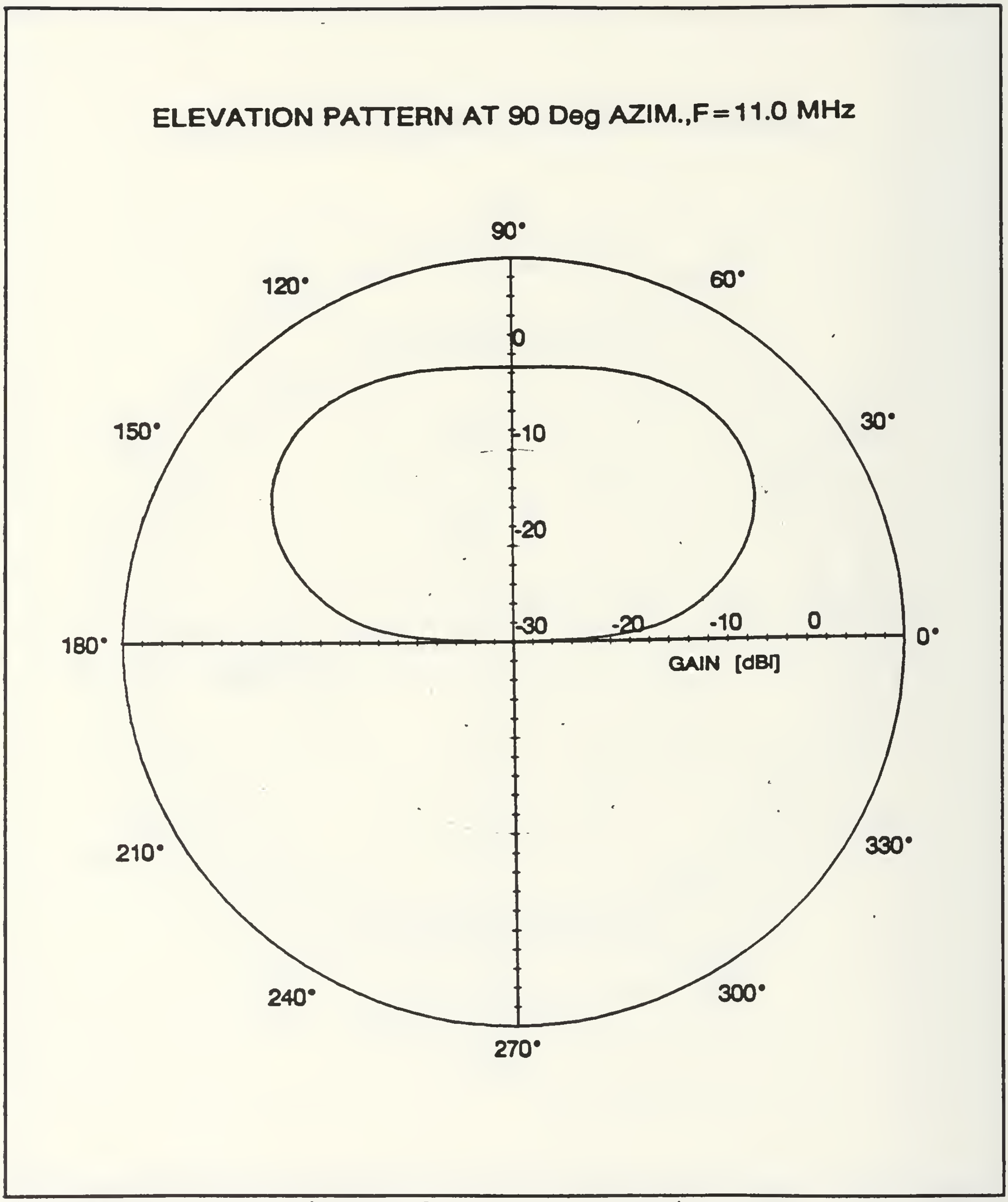

Figure 27: Elevation Rad. Pattern, Azim. 90°, f=11 MHz, Multiband Dipole Antenna at the NPS Beach site.

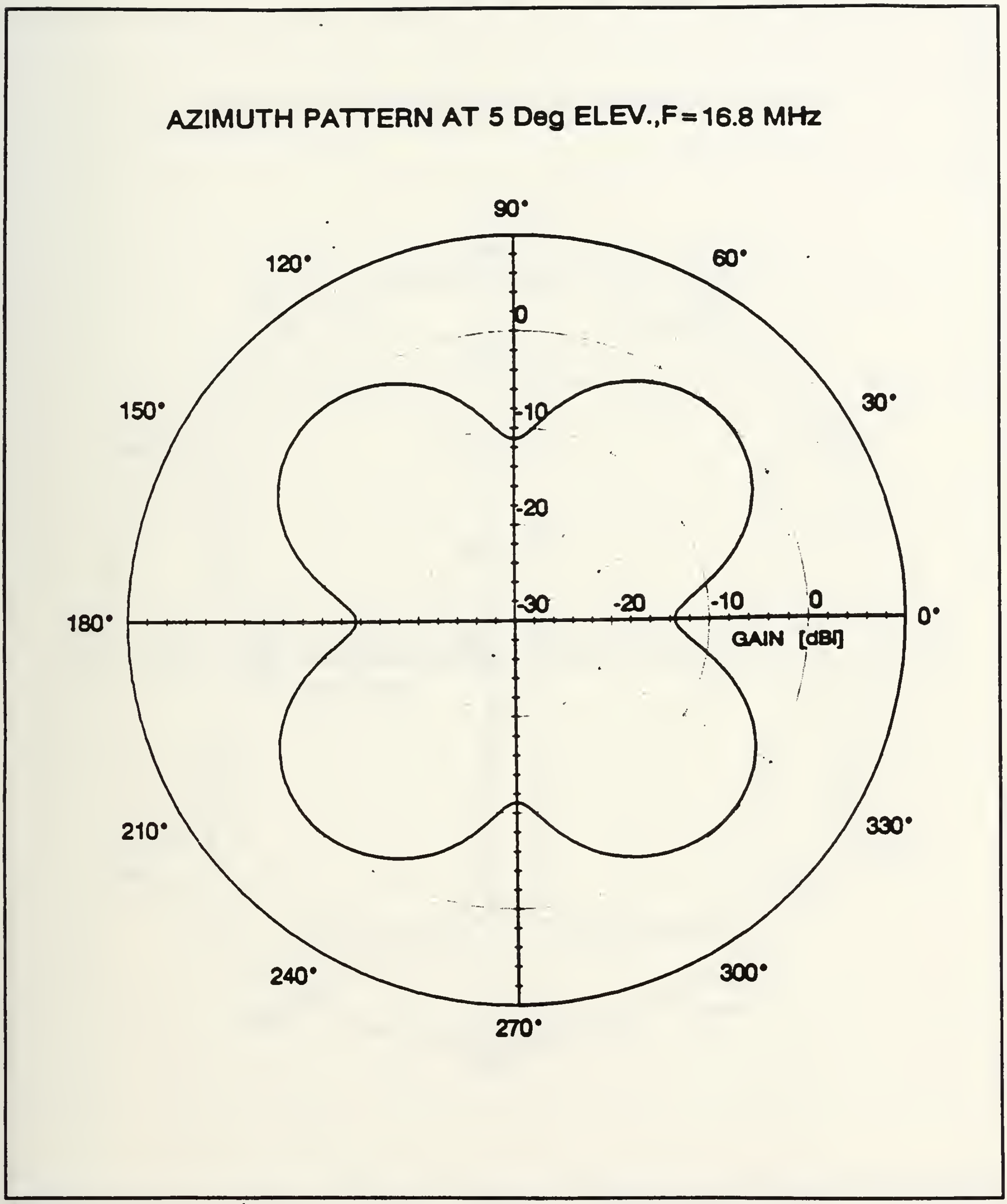

Figure 28: Azimuth Rad. Pattern, Elev. 5°, f=16.8 MHz, Multiband Dipole Antenna at the NPS Beach site.

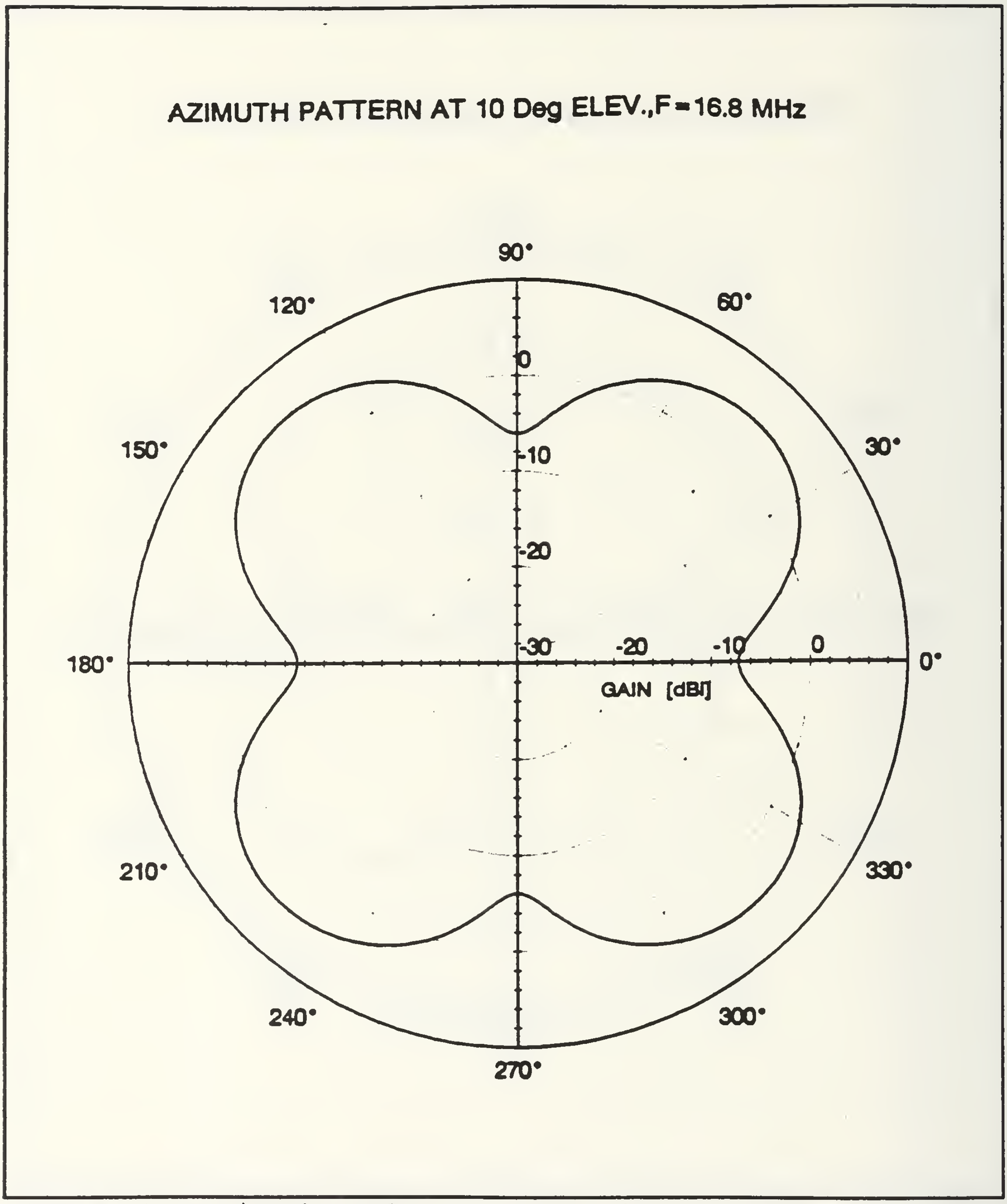

Figure 29: Azimuth Rad. Pattern, Elev. 10°, f=16.8 MHz, Multiband Dipole Antenna at the NPS Beach site.

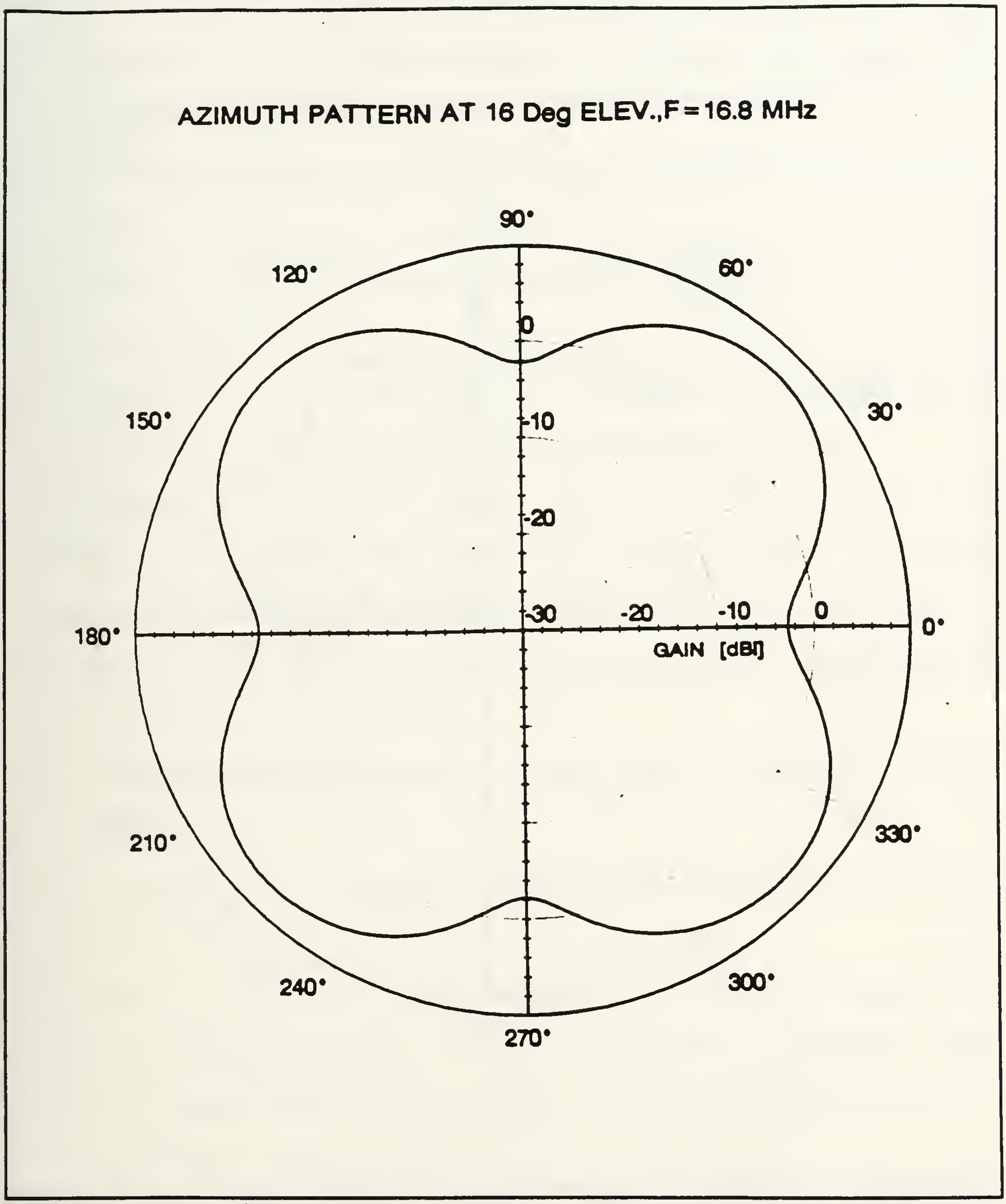

Figure 30: Azimuth Rad. Pattern, Elev.16°, f=16.8 MHz, Multiband Dipole Antenna at the NPS Beach site.

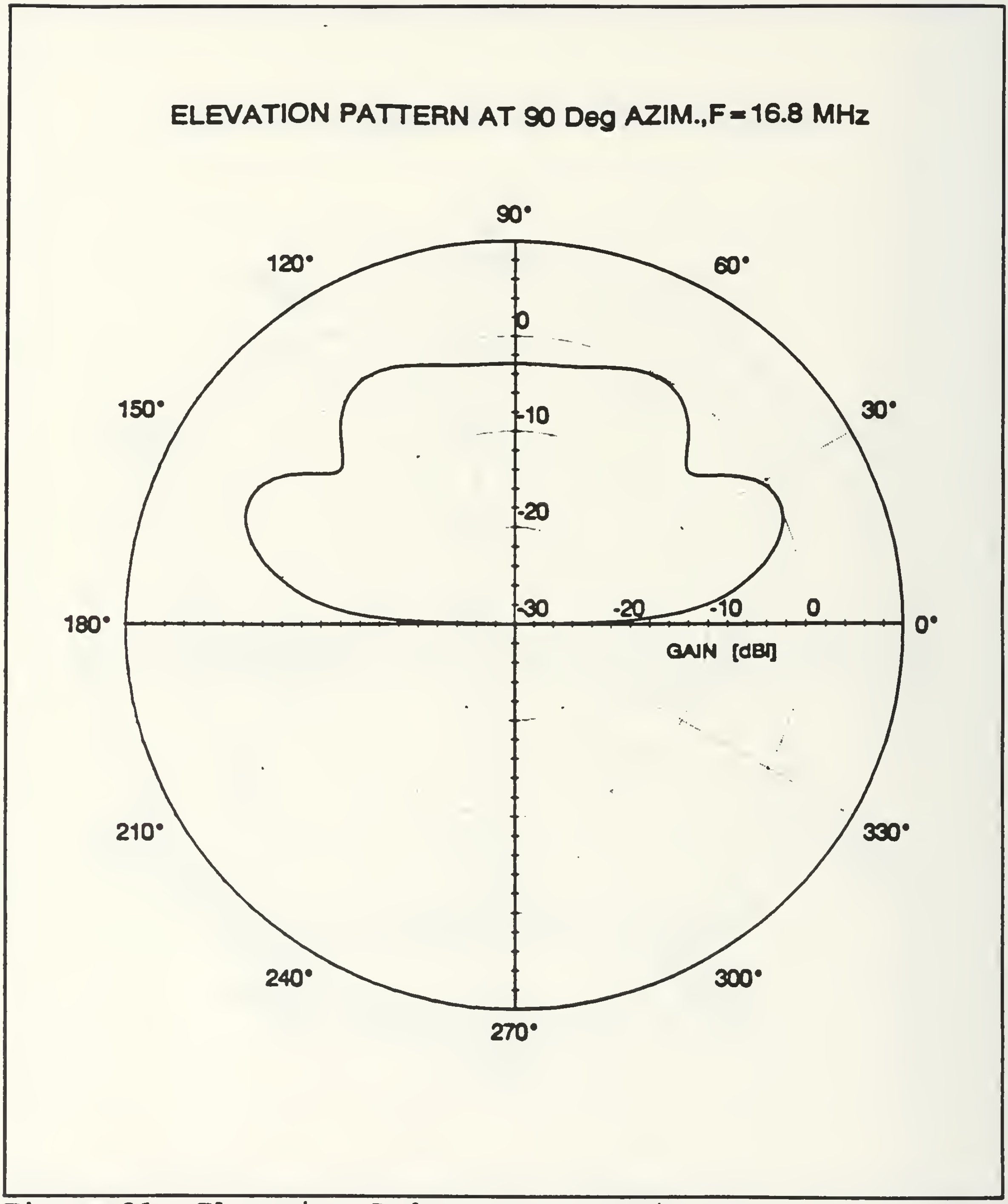

Figure 31: Elevation Rad. Pattern, Azim. 90°, f=16.8 MHz, Multiband Dipole Antenna at the NPS Beach site.

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